Concept Mapping Method on Students' Achievement in Science Education at Higher Level

Bishnu Kumar Dahal

A Dissertation for the Degree of Doctor of Philosophy in Science Education

Submitted to

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Concept Mapping Method on Students' Achievement in Science Education at Higher Level

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Dedication

I dedicate this dissertation to my late parents, father Kamala Prasad Upadhyay and mother Bal Kumari Devi, whose unwavering love, support, and sacrifices made it possible for me to pursue my academic dreams. I am forever grateful for the values and culture they instilled in me and the opportunities they provided me with. This dissertation is also dedicated to my entire Dahal family members who have stood by me through thick and thin, and have cheered me on every step of the way.

Moreover, I also dedicate this work to my wife, Nisha Sharma, who has been my pillar of strength and support. Her love, encouragement, and patience have been instrumental in helping me achieve my goals.

Last but not least, I dedicate this dissertation to my two wonderful daughters, Wagmi and Bibudh Dahal. You both have been my source of inspiration and motivation, and have reminded me of the importance of hard work and perseverance. This accomplishment is as much yours as it is mine.

Thank you all for your love, support, and sacrifices. I am grateful to have you in my life."

Declaration

I, Bishnu Kumar Dahal, hereby declare that this dissertation is my own original work and has not been submitted for any other degree or qualification at any other university or educational institution. The research and analysis presented in this dissertation have been conducted under my supervision and with the guidance of my research supervisor. All sources of information used in this dissertation have been properly cited and acknowledged. I further state that any ideas or views contained in my dissertation are entirely my own and do not represent the views of the institution or any of its affiliates. My dissertation will be submitted to the Tribhuvan University Central Library as a permanent collection. By signing below, I authorize the distribution of this dissertation to any reader who requests it.

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Bishnu Kumar Dahal

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Recommendation

I recommend the dissertation entitled "Concept Mapping Method on Students' Achievement in Science Education at Higher Level" submitted by Bishnu Kumar Dahal for acceptance as a requirement for the Doctor of Philosophy in Science Education. Throughout his academic journey, Bishnu Kumar Dahal has demonstrated a high level of dedication and commitment to his research work, particularly in the field of science education. His dissertation on the "Concept Mapping Method on Students' Achievement in Science Education at Higher Level", is a remarkable contribution to the field of science education.

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I had the opportunity to review his dissertation and was impressed by the thoroughness of his research, the clarity of his writing, and the validity of his findings. His research work sheds new light on the use of concept mapping method in science education and I believe it has the potential to bring significant improvements to science education practices in Nepal and beyond. Based on my evaluation of his work, I am confident that Bishnu Kumar Dahal has met all the necessary requirements.

Therefore, I highly recommend his dissertation for acceptance, and I am confident that his work will make a valuable contribution to the academic community.

KMaharjan

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Approval

This dissertation entitled “Concept Mapping Method on Students' Achievement in Science Education at Higher Level” by Bishnu Kumar Dahal for the Doctor of Philosophy in Science Education has been approved.

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Moreover, I would like to thank my family for their unwavering love, encouragement, and sacrifices. Their constant support, faith, and belief in me have given me the strength to persevere and overcome the challenges of graduate school.

Lastly, to all the individuals who have contributed to my PhD journey in one way or another, I offer my sincerest gratitude. Your support, encouragement, and guidance have been indispensable in helping me achieve this significant milestone.

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Abstract

This research, titled "*Concept Mapping Method on Students' Achievement in Science Education at Higher Level*," examined the impact of the concept mapping teaching method on bachelor-level science students' achievement, comparing it to conventional methods and assessing its effectiveness across four cognitive levels: knowledge, understanding, application, and higher-order thinking. Conducted using a quasi-experimental "pre-test, post-test, non-equivalent group" design with mixed-method approach, the research took place at Mahendra Ratna Campus and Sano Thimi Campus, Tribhuvan University, located in Kathmandu and Bhaktapur districts, Nepal respectively. A total of 165 students participated, with the experimental and control groups (70 students in the control group and 95 students in the experimental group) chosen randomly. The study focused on topics like Electrostatics and Direct Current circuits in the second year of bachelor-level science education. Additionally, 8 students from the experimental group and 4 from the control group were selected for interviews through purposive sampling to explore non-cognitive factors. The teacher sample comprised 7 physics teachers, with 5 from the experimental campus and 2 from the control campus, also selected purposively.

To verify the validity and reliability of the study tools, a pilot test was conducted at a campus outside the main study. Forty multiple-choice questions were created for the achievement test, achieving a reliability score of 0.79, calculated with the Kuder-Richardson-21 formula. These test items were developed in alignment with the specified curriculum and were finalized following consultations with experts in science education. Additional tools, including observations, checklists, and reflective diaries, were tested for reliability using the test-retest method. The validity of all tools was confirmed by the supervisor.

Quantitative data were collected using the Physics Achievement Test (PAT) with pre-tests and post-tests to assess student achievement. The data were analyzed using SPSS version 20. Following the intervention, a post-test was conducted for all students. The independent samples test showed a significant difference in post-test scores, with the experimental group outperforming the control group by 4.237 points ($p < 0.001$). ANOVA confirmed significant differences in all cognitive domains: Knowledge ($p < 0.001$), Understanding ($p < 0.001$), Higher Level ($p < 0.001$), and Application ($p = 0.001$), highlighting the effectiveness of the concept mapping method.

Regarding gender differences, significant differences were found in Knowledge ($t = 2.093$, $p = 0.038$) and Application ($t = 2.361$, $p = 0.019$), but no significant differences were observed in Understanding ($t = 1.385$, $p = 0.168$). The Higher Level domain approached significance ($t = 1.979$, $p = 0.049$).

Qualitative data, encompassing interviews, diaries, and observations of both students and teachers, were analyzed using ATLAS.ti 9. These findings revealed that the concept mapping method significantly enhanced physics achievement, fostering creativity, ownership, and critical thinking, in contrast to the control group's reliance on rote memorization. Despite its effectiveness, challenges such as the complexity of electric circuits and numerical problems were noted. The study highlighted the need for improved teacher training, strategies that link concepts to real-world applications, and language support. The concept mapping approach contributed to a collaborative learning environment, ultimately enhancing student engagement and achievement in physics education. These findings offer valuable insights for researchers, teachers, and students aiming to improve academic performance in science education.

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Abbreviations

AFU : Agriculture and Forestry University

ANCOVA : Analysis of Covariance

ANOVA : Analysis of Variance

B.Ed. : Bachelor of Education

B.Sc. : Bachelor of Science

BC : Before Christ

BPKIHS : BP Koirala Institute of Health Sciences

CBEGRA : Classroom-Based Early Grade Assessment

CDC : Curriculum Development Center

CEHRD : Center for Education and Human Resource Development

CERSOD : Center for Educational Research and Social Development

CTEVT : Council for Technical Education and Vocational Training

DoE : Department of Education

DOI : Digital Object Identifier

ECD : Early Childhood Development

EDCU : Education Development and Coordination Unit

ERO : Education Review Office

FOE : Faculty of Education

FWU : Far Western University

GU : Gandaki University

ICT : Information Communication Technology

KAHS : Karnali Academy of Health Sciences

KU : Kathmandu University

LBU : Lumbini Buddhist University

M.Ed.	:	Master of Education
M.Phil.	:	Master in Philosophy
M.Sc.	:	Master of Science
MoEST	:	Ministry of Education, Science and Technology
MU	:	Mid-Western University
NAMS	:	National Academy of Medical Sciences
NASA	:	National Assessment of Students' Assessment
NCF	:	National Curriculum Framework
NEB	:	National Examination Board
NOU	:	Nepal Open University
NSU	:	Nepal Sanskrit University
OCOE	:	Office of Controller of Examinations
ODL	:	Open Distance Learning
PA	:	Performance Audit
PAHS	:	Patan Academy of Health Sciences
PBL	:	Problem Based Learning
PCL	:	Proficiency Certificate Level
PG	:	Post-graduation
Ph.D.	:	Doctor of Philosophy
PIRLS	:	Progress in International Reading Literacy Study
PISA	:	Program for International Student Assessment
PokAHS	:	Pokhara Academy of Health Sciences
PokU	:	Pokhara University
PU	:	Purbanchal University
RJU	:	Rajarshi Janak University

SEE : Secondary Education Examination

SLC : School Leaving Certificate

SLSC : Secondary-Level Science Curriculum

SPSS : Statistical Package for the Social Sciences

SSDP : School Sector Development Plan

SSRP : School Sector Reform Plan

STEAM : Science, Technology, Engineering, Arts, and Mathematics

TIMSS : Trends in International Mathematics and Science Study

TSLC : Technical School Level Certification

TU : Tribhuvan University

UG : Under-graduation

UGC : University Grants Commission

UK : United Kingdom

VM : Vee-mapping

Chapter I

Introduction

Background of the Study

The conventional perception of science is the study of facts pertaining to the material and natural worlds. However, attitudes toward science education have shifted, moving away from a purely fact-based approach to one that prioritizes practical actions tailored to the abilities, perspectives, beliefs, and understanding of learners (Donnelly & Jenkins, 2001). Science now encompasses a set of cognitive activities that include emotional participation and hands-on experience. Nonetheless, several hurdles exist in Nepal that impact students' beliefs and actions regarding science education.

Science education is often seen as abstract and distant from everyday experiences. Chemistry and biology students struggle with heavy memorization, while physics and mathematics students find it difficult to connect abstract concepts to practical applications. As a result, many fail to recognize that science is embedded in nature and that the scientific method is a valuable tool for understanding and solving real-world problems. Instructional approaches in science education should shift from being centered on scientists to being centered on learners, delivering engaging and relevant content that caters to all children, not just those aspiring to become scientists (Rennie et al., 2001).

One significant challenge is the nature of science textbooks, which emphasize facts over personal connection and appeal. According to Osborne and Collins (2001), science appears challenging and tedious to students due to the abstract concepts and scientific vocabulary in textbooks. Students find no connection between the subject and their social and personal lives, leading to a loss of interest. Additionally, the teacher's authority in the traditional science classroom plays a role. Teachers, viewed as the sole sources of information, bear the responsibility of transmitting knowledge to students (Tobin & McRobbie, 1997). Consequently, students rarely have any authority in science classrooms. Traditional teachers often emphasize the importance of essential knowledge and skills for students' future careers, leading them to favor conventional teaching methods.

The high-stakes evaluation system significantly impacts instructors' methods, granting them control over job satisfaction, content delivery, and coverage, as well as information transmission. Conversely, public examinations restrict instructors' autonomy in selecting and delivering topics. Teachers face pressure to cover all information within tight time constraints, often at the expense of student engagement and learning (Chapagai, 2023).

Another factor to examine is the scope and nature of practical experience in science classrooms. Several investigations have emphasized the importance of engaging hands-on and minds-on activities to impart a diverse set of scientific skills, ranging from fundamental computational abilities to advanced analytical skills (Bekalo & Welford, 2000; Osborne & Collins, 2001; Watts, 1991). Additionally, science education can be seen as a division between educational activities within science and those aimed at the non-scientific public (Rudolph, 2008). Wallace et al. (2002) emphasize the necessity of true practical work in bridging the gap between school and real science. However, most school laboratories limit updated teaching strategies to repetitive tasks with pre-determined solutions (Donnelly & Jenkins, 2001; Zin, 2003). The narrow scope and infrequent use of practical activities stem from teachers' limited expertise in designing and conducting inquiry-based projects, as well as assessment systems that adhere strictly to prescribed textbook procedures.

In many educational institutions, practical work is often deprioritized due to its time-consuming nature, minimal weight in overall examinations, and the challenge of managing large classes with inadequate resources.

Moreover, science curricula globally often separate subjects into physics, biology, and chemistry, seldom exploring the connections between them. Common issues in exams include memorization, rote learning, and focusing on key terms. Many students tend to see schooling as a challenge to be conquered, rather than a journey towards intellectual growth (Kwok, 2018).

Education System in Nepal

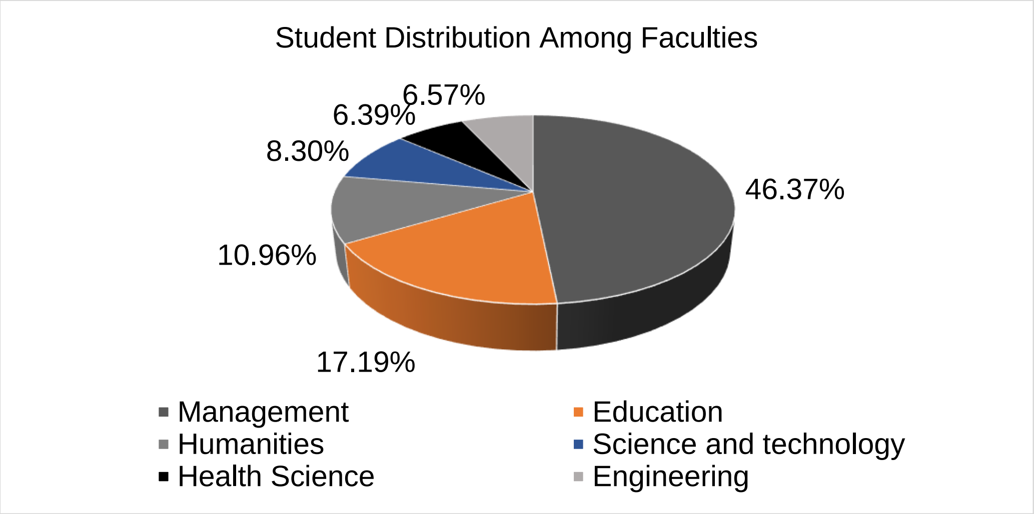
Nepal's educational system ranges from basic school to university level, encompassing a diverse array of institutions. According to the Center for Education and Human Resource Development (CEHRD, 2022), the country has 35,969 schools, including 27,890 community schools, 6,926 institutional schools, and 1,153 religious institutions, as well as over 1,408 colleges. A significant portion of the population attends school, with most children starting around age three. Early childhood education, although critical, remains limited, with 36,926 Early Childhood Development (ECD) centers available nationwide as of 2022, predominantly in urban areas. Formal schooling is divided into basic (grades 1-8) and secondary (grades 9-12) levels, with enrollments of 5.44 million and 1.77 million children respectively, demonstrating a higher attendance in primary education compared to secondary and university levels (CEHRD, 2022; Pal et al., 2021). The Ministry of Education oversees the system, supported by various regulatory bodies managing curriculum and examinations.

Higher education in Nepal is extensive, with twelve universities and five medical academies providing a various program, from Bachelor's to PhD levels.

Tribhuvan University (TU) is the largest, accounting for 76% of the university student population, with the majority of students enrolled in management subjects (46.37%), followed by education (17.19%) and humanities (10.96%). Additionally, 8.38%, 6.39%, and 6.57% of student's study science and technology, health science, and engineering, respectively (UGC, 2020). Other universities like Kathmandu University, Pokhara University, and Purbanchal University also contribute significantly to higher education, providing courses across diverse fields such as sciences, humanities, management, and technology, adhering to both annual and semester systems (UGC, 2022). Vocational education, managed by the Council for Technical Education and Vocational Training (CTEVT), offers practical skills through diploma and certificate courses in various sectors. Post-graduate education, ranging from 2 to 5 years, allows for specialization in specific disciplines (CTEVT, 2022). Despite the challenges, Nepalese universities strive to deliver high-quality education, meeting international standards and adapting to modern teaching methods, including e-based learning through the National Open University (UGC, 2022).

Figure 1

Student distribution among faculties at the higher education level in total



Source. Adapted from the report of UGC (2020)

Recent Status of Science Education in Nepal

Science, as a human endeavor, seeks to achieve an objective understanding of the world. It is often described as the study of information concerning the natural and material world. Scientific advancement drives a nation's economic and social development. This progress can be fostered through well-structured science education that meets the needs of the population.

The Faculty of Education at Tribhuvan University (TU) offers a four-year B.Ed. program in science education, a one-year B.Ed. program in science education designed for B.Sc. graduates, and a two-year M.Ed. program in science education. This M.Ed. program offers specialized tracks in physics education, chemistry education, and biology education within a semester system. The overarching aim is to cultivate skilled individuals for teaching positions in both school and university settings (Paudel & Rajbhandary, 2022). The Faculty of Education has launched a three-semester M.Ed. program in science education through Open Distance Learning (ODL) mode for M.Sc. graduates who are interested in or currently seeking a career in teaching and education. Furthermore, TU conducts a two - semester M.Phil. degree in education. TU makes a substantial contribution to the production of competent human resources for the education sector.

Likewise, Kathmandu University's School of Education has approved a three-semester M.Phil. program in STEAM Education (Science, Technology, Engineering, Arts, and Mathematics). In addition, Purbanchal University's Institute of Open Learning and Nepal Open University's Faculty of Social Sciences and Teaching offer a one-year B.Ed. program in science education for B.Sc. graduates through distance learning (Paudel & Rajbhandary, 2022).

Bachelor Level Science Education Curriculum of Nepal

The Curriculum Development Center (CDC), an in-house academic body, is responsible for developing curricula, teacher guides, textbooks, and other instructional resources for school education. The school curriculum is in line with the National Curriculum Framework (NCF) for School Education 2019, which has been approved by the Ministry of Education, Science, and Technology (MoEST).

Science is provided in schools beginning in first grade. At the primary level (grades 1-3), science is integrated with other subjects like health and physical education, social studies, moral science, and creative arts activities. Science and technology are integrated (5 credit hours) in grades 4-10. In addition, students in grades 9 and 10 can select one more science (4 credit) topic as an elective. Subject-specific sciences such as physics, biology, chemistry, environmental science, computer science, and others are available as electives in grades 11 and 12. Universities provide general science and applied science courses at the bachelor's, master's, and doctoral levels (Paudel & Rajbhandary, 2022).

The science education curricula in schools and colleges are heavily focused on factual information, often delivered through traditional teacher-centered lectures that emphasize memorization and rote learning. Assessments predominantly promote the reproduction of knowledge. Despite being a curriculum requirement, practical experiments in schools are often neglected. Textbooks are sometimes the only materials accessible to students for science instruction. Textbooks are heavily packed with factual information, with a focus on descriptive rather than practical scientific understanding (Paudel & Rajbhandary, 2022).

The Bachelor level in science education curriculum by Faculty of Education (FOE) for Physics, spanning a four-year period, encompasses diverse topics in a meticulously structured manner. A content analysis of the four-year B.Ed. in Science Education curriculum reveals that in the first year, the curriculum focuses primarily on mechanics, which constitutes 53.33% of the content, followed by heat, geometrical optics, and astronomy at 16.67%, 16.67%, and 13.33%, respectively. In the second year, the study of waves and sound constitutes 20% of the curriculum, while physical optics, electricity, and the vast realm of the universe encompass 26.67%, 43.33%, and 10%, respectively. Progressing to the third year, electromagnetism emerges as the predominant theme, occupying 46.67% of the curriculum, accompanied by modern physics at 43.33% and digital electronics at 10%. Finally, in the fourth year, the syllabus covers energy and fuels (26.67%), classical mechanics (26.67%), atomic physics (13.33%), particle physics (15.33%), optoelectronics (4.67%), and the intriguing domains of plasma physics and cosmology, both constituting 13.33% (FOE, 2020).

Individuals who move from university graduates to teachers sometimes exhibit a lack of conceptual knowledge and analytical ability in the fields of science and research after completing their master's degree. As a result, they can become ineffective science teachers, providing low-quality instruction. Merely possessing a degree is inadequate, as these individuals must also acquire the necessary professional skills that are expected of science teachers in the 21st century (Kind, 2014).

Teaching methods and materials

Teaching physics in a school setting is both exciting and challenging. Schoolchildren can better comprehend physical concepts when taught using appropriate methods and resources. There are several approaches to effectively teaching and studying physics, with the best method chosen based on the aims and nature of the physical concepts. Depending on the purpose and nature of the lesson, multiple instructional methods may be employed in the same lesson (Pattnaik et al., 2015). Different teaching strategies foster various student talents, making the successful outcome of physics instruction reliant on the selection and implementation of suitable methods and activities. Effective teaching strategies and tasks can inspire learners to participate actively in the learning process. To become an effective teacher, one must understand the link between physics material and various teaching approaches for delivering a lesson.

The Secondary-Level Science Curriculum (SLSC) emphasizes students' activities in teaching-learning physics. Activity-based topics in the SLSC include demonstrating force and motion, simple machines, pressure, energy, heat energy, waves, and electricity and magnetism. Instructional strategies are methods for achieving set educational goals. Effective teaching tactics are crucial for improving student performance in internal and external examinations. This study highlights learning-to-learn competency, which enables students to manage their learning independently and effectively based on one's objectives and needs. According to Romero et al. (2017), this competency involves thinking about one's own learning and making adjustments to improve it. Therefore, instructional methods can be defined as tools to facilitate and enhance studying, aiming to maximize academic success.

Traditional teaching method

The lecture method is the most traditional form of instruction, where the teacher actively delivers the subject matter to students. To enhance engagement, teachers use gestures, simple teaching aids, voice modulation, movement, and facial expressions. While teachers play a more active role, they frequently ask questions to maintain student attention. According to Rahman and Masuwai (2014), the most commonly used technique of teaching is the lecture method, and the typical style of lecturing usually refers to a single-direction learning pedagogical model in which the students are merely recipients of knowledge and the lecturer is the source of knowledge. The responsibilities are clear: The knowledgeable lecturer tells students who don't know all they need to know. A teacher speaks, and students pay attention. The lecture method has long been the dominant approach to content delivery, particularly in tertiary education institutions. This technique is often referred to as the chalk-and-talk approach.

Existing practices of teaching Science in Nepal

Science instruction in Nepal is heavily influenced by theoretical aspects, hence classroom engagement is unrelated to students' real-life conditions (Acharya, 2016). A rigid method of teaching science makes students experience bored, and as a result, they are more likely to memorize the reading contents. Science classes are less engaging and focused on teamwork because teachers tend to be more theoretically motivated. When dealing with science topics, conventional approaches, and procedures are frequently used. Another source of worry in Nepalese schools is the size of the class. The individual desires of the teacher are unable to maintain the class size. It encourages teachers to use conventional methods of instruction, such as the lecture method. Since mass teaching practice is commonly employed in scientific classrooms (Rani, 2017), the conventional role of the teacher is specified, primarily as the source of knowledge and the single decision-maker of the teaching-learning process. Students are more regulated, and they serve as passive consumers of the knowledge that teachers provide. Thus, students are passive listeners, and the teacher's job is to pour his or her expertise into the empty vessels, i.e., the minds of passive students. The science teacher is typically considered to be a problem-solver and knowledge bank in classroom teaching and learning situations. It not only hinders interactive teaching approaches in scientific classrooms, but it also has a negative impact on students' awareness (Freire, 2018).

A quiet classroom is seen to be the greatest option in our circumstances for teaching and learning. This is because the instructor plays a key role in the teaching process within the classroom. Classroom interactions are discouraged by instructors and school authorities. According to Freire (2018), the banking notion transforms individuals into objects by taking the responsibilities of teachers as bankers and students as receptors. Humans (as objects) lack autonomy and so lack the ability to analyze and understand information on an individual level. Because of this original mistake, the approach itself is an oppression and control mechanism.

Physics is a natural science that investigates matter, its mobility, and behavior in space and time (Feynman et al., 1963), as well as the associated phenomena of energy and force (Maxwell, 1925). It generates essential knowledge and enhances our standard of living. Teaching physics at the secondary and higher levels is a difficult task that requires a lot of passion and innovative problem solving. It entails assisting pupils in developing new perspectives on the world. It involves establishing a learning environment where students can investigate and understand the workings of the physical world, while also connecting complex scientific concepts to their everyday experiences. It entails instilling student confidence in their ability to tackle difficult challenges and equipping them with the tools they need to create a better future for themselves and others. As a result, good physics instruction needs creativity, thought, and a thorough understanding of not only physics but also psychology, cognition, and communication (Wenning & Vieyra, 2020).

In science classrooms, diverse learning strategies are employed to assist students in overcoming certain challenges associated with learning science. Learning methods refer to the activities students engage in to enhance their acquisition of new knowledge more efficiently (Liou, 2009). Students who utilize learning techniques during academic activities perform better than students who do not employ learning strategies, according to Harrison et al. (2003). Highlighting, jotting down notes, engaging in discussions with fellow learners, and creating outlines are among the learning strategies implemented in science classrooms to actively involve students in the learning process (Hilbert & Renkl, 2008).

Furthermore, throughout the years, numerous software programs have been created to visually represent connections among facts, concepts, and ideas. These mapping techniques have been referred to by various names such as "thought mapping," Vee-Mapping, "conceptual diagram," and "concept mapping." Every mapping strategy has the same goal in mind. Students learn better and remember complex concepts when they can show or change them using diagrams. This helps them understand the topic deeply instead of just memorizing it (Biggs, 1987; Entwistle, 2013; Johnson et al., 2013; Marton & Saljo, 1976a, 1976b). Secondly, maps are usually easier to understand than written or spoken explanations, but their quality can differ, so it’s important to choose the right type (Larkin & Simon, 1987; Mayer & Gallini, 1990). Thirdly, creating maps requires students to actively engage with the material, which helps them understand, analyze, and retain the content more effectively, leading to improved learning outcomes (Twardy, 2004). Mapping has been shown to enhance learning by helping students better organize and retain information. Research from the cognitive sciences (Vekiri, 2002; Winn, 1991) supports this idea, indicating that visual tools like maps can make complex information easier to understand and remember, leading to improved knowledge retention and learning outcomes. These visual displays provide a clear, organized way to present concepts, making it easier for learners to make connections and strengthen their understanding.

Mind mapping

'Visual, non-linear representations of ideas and their interactions' is how mind mapping (or 'idea' mapping) is defined (Biktimirov & Nilson, 2006). A network of connected and related concepts is represented by a mind map. In mind mapping, however, any notion can be linked to another. When constructing a mind map, it’s important to think freely and spontaneously to make creative connections between concepts. Consequently, mind maps primarily function as association maps. Buzan was the first to use formal mind mapping techniques, which included line widths, colors, drawings, and diagrams to assist information memory (Buzan, 1983; Buzan & Buzan, 2000).

Mind mapping has the benefit of being flexible, allowing unlimited thoughts and connections without needing a specific structure. This encourages creativity and brainstorming. However, the relationships formed in mind maps are usually simple connections. Mind maps are often regarded as distinctive in design, sometimes posing challenges for others to interpret; displaying primarily hierarchical linkages, often in a radial form; varying inconsistently in the amount of information presented; and frequently being overly intricate, potentially missing the overarching "big picture" (Eppler, 2006). Despite these limitations, the ability of mind mapping to promote divergent thinking and visually organize information remains a significant advantage, particularly in educational settings where creative problem-solving and complete understanding are essential.

Vee-mapping

Vee-mapping (VM) is another educational technique that helps students' discovery and puts them in control through self-inquiry, peer interaction, and hands-on experiences. Vee-mapping was invented and developed by Gowin and Novak to enable learners understand the structure of knowledge (e.g., rational networks, hierarchies, combinations) and process of knowledge construction (Mohammed & Samuel, 2021). Novak (1990b) agrees that VM helps students through investigations in the same way as concept mapping does; nevertheless, this less-structured investigative arrangement allows students to actively acquire the principles of investigation. The VM is made up of two interconnected structures: the left (Larkin & Simon, 1987) and right (psychomotor) sides of the Vee. The VM method will assist students in comprehending the nature and purpose of laboratory activities, as well as how new knowledge is acquired in an experimental setting (Novak, 2010). The Vee-maps are of great benefits to teaching and learning situations, procedures and processes which in turn the researcher is trying to see how it possess the capacity to improve students’ achievement and retention.

This method's emphasis on active learning and self-inquiry can transform traditional classroom dynamics, making science education more interactive and student-centered. By promoting a deeper grasp of scientific concepts and encouraging students to take responsibility for their learning process, Vee-mapping enhances knowledge retention and strengthens students' critical thinking and problem-solving abilities. This approach ultimately empowers students, leading to a more profound and lasting understanding of the material, thereby contributing to more effective and meaningful science education.

Conceptual diagram

With the use of pre-defined categories, a conceptual diagram employs a graphic conceptual framework to visually organize and present information or learning content, making it easier to understand and connect key concepts. The categories are frequently developed from a theory or model (domain-specific) (Huff, 1990). As graphic elements, labeled boxes and arrows with integrated text (if needed: icons) can be used to give instructional information. Furthermore, the primary purpose of a conceptual diagram is to study a topic or situation using a well-established analytical framework (Eppler, 2006). It can be applied in the same way to a variety of circumstances and provides a brief overview (Tufte et al., 1990). A downside of conceptual diagrams is that they can be difficult to comprehend without prior knowledge of category definitions and may not be pertinent to the topic at hand. It also does not encourage creativity or self-expression (Eppler, 2006).

Although teachers currently use various learning strategies to help students understand science content, they may not always encourage the integration of prior knowledge with new concepts to foster meaningful learning (Hilbert & Renkl, 2008). Concept mapping, on the other hand, is a structured learning approach that is less visually-oriented, requiring students to illustrate the interconnectedness of a set of concepts and integrate new information with their existing knowledge to promote meaningful learning (Plotnick, 2001). Students need to draw on prior knowledge and evaluate the relevance of new information to their existing understanding of a topic. Utilizing the concept mapping learning method allows students to establish visual connections between pieces of knowledge, facilitating a deeper understanding of the subject (Aidman & Egan, 1998). Comparative assessments of the effectiveness of concept mapping against the mentioned learning approaches reveal that students employing concept mapping as a learning strategy perform better on science tests than those using highlighting, note-taking, engaging in debates with co-learners, or outlining (Hilbert & Renkl, 2008). Additionally, the concept mapping learning approach contributes to the identification of students' misconceptions. Students' degree of understanding is revealed through concept maps created by them. Teachers and students can examine concept maps to discover flaws, allowing teachers to correct them before students try to create scientific knowledge derived from faulty data.

Concept Mapping in Science

There is considerable research on using concept mapping as a learning method to acquire scientific knowledge. Bulunuz and Jarrett (2009) and Clariana and Koul (2008) investigated the effectiveness of collaborative concept mapping in enhancing students' science achievement. Their studies highlighted how engaging in collaborative mapping activities allowed students to better organize, clarify, and discuss scientific concepts, leading to improved understanding. In contrast to concept mapping groups lacking students with substantial prior knowledge in the subject matter, Clariana and Koul (2008) found that concept mapping groups comprising graduate education students with prior expertise in the content area produced more complete concept maps. The effectiveness of three concept mapping methods—concept identification, proposition identification, and student-created concept mapping—was investigated to assess the academic achievement of undergraduate students. The studies revealed that the groups utilizing concept identification outperformed those using student-created and proposition-identifying concept mapping approaches in both studies (Wang & Dwyer, 2004, 2006).

Assessment and Examinations

Assessment is regarded as a crucial component of the curriculum, with the Curriculum Development Center (CDC) responsible for designing the assessment framework for school education. The shift from a percentage-based evaluation system to a letter grading system has been introduced from the foundational level to the secondary level, extending up to grade 12. A subject-specific specification grid is utilized at all levels to guide the development of assessment tools.

The Nepalese education system emphasizes both formative and summative assessments, as outlined in education policies, curricula, and teacher training programs. As per the Education Act of 2019, the local government administers the basic-level examination at the completion of basic education (grade 8), followed by the Secondary Education Examination (SEE) at the end of grade 10. Furthermore, a national examination at the end of the secondary level (grade 12) is conducted under the supervision of the National Examination Board (NEB). Students' assessments incorporate formative evaluation methods, including classwork, project work, community engagement, unit tests, observations, and creative assignments; however, these are not considered in district and national-level final assessments. Various authorities, such as schools, municipalities/rural municipalities, the provincial examination office, and the Office of the Controller of Examinations (OCOE), are responsible for administering these exams at different levels.

In higher education, assessments comprise both internal evaluations and final examinations, conducted at the end of each semester or academic year. Universities manage student evaluations through their respective examination controller offices. Depending on the academic level, different universities implement annual systems, semester systems, or a blend of both, each following distinct evaluation structures and methods. Efforts have been made by institutions like Tribhuvan University (TU) to embrace more progressive assessment approaches. Since 2012, TU has reintroduced the semester system, wherein students undergo internal evaluation (40%) conducted by their respective campuses/departments and external evaluation (60%) overseen by the relevant office of the dean under the Office of the Controller of Examinations (TU, 2013).

At the national level, Nepal has established its own assessment system under the supervision of the Education Review Office (ERO) rather than engaging in international high-stakes assessments like the Program for International Student Assessment (PISA), Trends in International Mathematics and Science Study (TIMSS), and Progress in International Reading Literacy Study (PIRLS). A study by the Center for Educational Research and Social Development (CERSOD, 2016) found Nepal unprepared to participate in such assessments due to policy and legal constraints, financial limitations, and inadequate technical and institutional capacity.

The Education Review Office (ERO) established an assessment and audit framework, along with tools and standards, to evaluate school education nationwide. ERO carried out various studies, including the National Assessment of Students' Achievement (NASA), early learning and development assessments, classroom-based early grade assessments (CBEGRA), performance audits (PA) of schools and institutions, and educational research. Between 2011 and 2020, ERO conducted seven NASA studies, assessing students' learning in Nepali, English, Mathematics, and Science at grades three, five, eight, and ten. The NASA-2013 study was the first to include science, revealing a national average score of 41 out of 100 for grade 8 students. Subsequent NASA studies in 2017 and 2020 showed a decline in science achievement, with scores dropping from 500 to 470, indicating a decline in science learning outcomes.

Both reports depict disparity in learning science as per students' family background, socio-economic status, ethnicity, gender, home language, school types, home environment, province, etc. (Khanal et al., 2022). In both instances, girls demonstrate lower performance levels compared to boys.

In 2013, Madhesi students had an average achievement rate of 36%, which was lower than the national average of 41%. Students from urban areas outperformed their rural counterparts, with 57% compared to 37% in the NASA 2013 study. These findings indicate a need for focused attention on school science through educational reform initiatives to improve quality and promote equity in science education.

At the higher education level, past studies such as those by Mathema and Bista (2006) on School Leaving Certificate (SLC) performance have identified significant challenges in subjects like mathematics, science, and English. They revealed that these subjects had the highest failure rates, with performance disparities observed based on gender, ethnicity, and location. Such findings call for ongoing reforms to address these gaps and enhance educational outcomes.

This detailed analysis of assessment practices highlights the evolving needs and challenges at different educational levels, from school to higher education. While school-level assessment forms the foundation for lifelong learning, higher education assessment frameworks aim to develop specialized competencies required in professional fields. Addressing gaps at both levels through reforms and innovations can ensure a more effective and equitable education system in Nepal.

Academic Achievement in Science Education

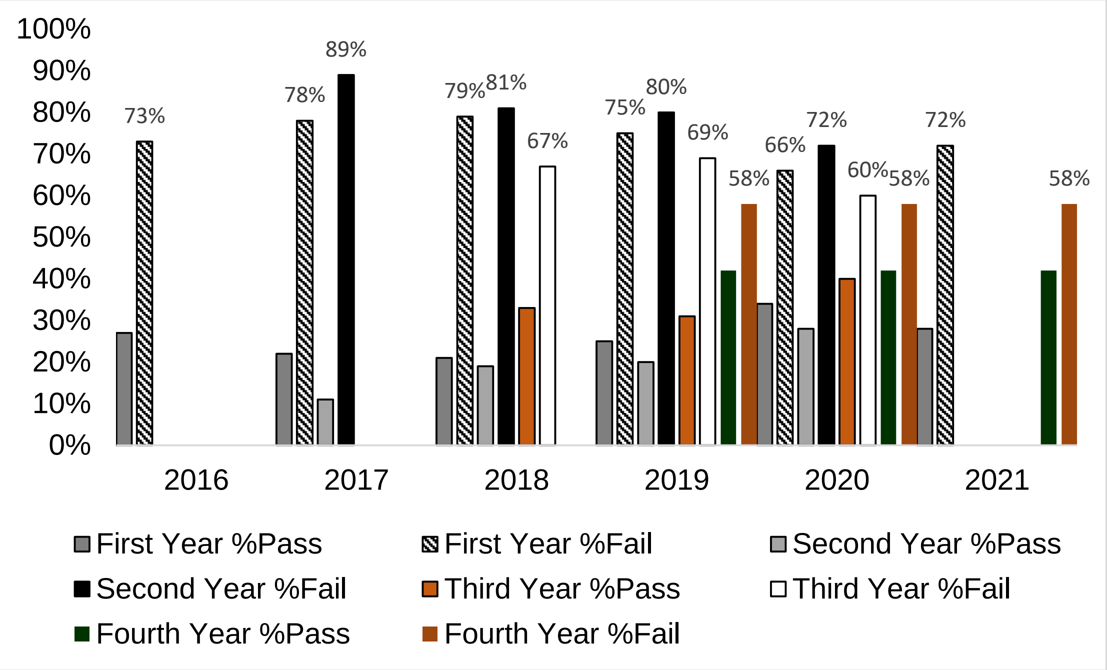
Academic achievement is an important indicator for assessing the effectiveness of educational practices, especially in the field of science education in Nepal.

It encapsulates the results of student performance, showing how well students meet predefined educational objectives, and thus reflects both personal competence and the success of the institution (Steinmayr et al., 2014; Talib & Sansgiry, 2012). As a fundamental outcome of the educational process, academic achievement is not only pivotal for students' immediate educational trajectories but also for their long-term career aspirations in an increasingly competitive global landscape (Ali et al., 2013).

In the realm of higher education in Nepal, significant disparities in academic achievement have been documented. Recent statistics from the Office of the Controller of Examinations (OCOE, 2023) reveal that pass rates during the four-year Bachelor of Education (B.Ed.) program in science education have fluctuated between 11% and 42%, with failure rates reaching as high as 89% in certain years. The comparative analysis of failure rates between 2020 and 2021 shows some notable trends. In 2021, the first year failure rate increased to 72%, up from 66% in 2020, reflecting a 6% rise in failures. The increase in the first-year failure rate suggests potential factors that may have influenced student outcomes in 2021, which warrant further investigation. These alarming statistics highlight systemic inefficiencies in traditional pedagogical methods, particularly in subjects such as physics, where students frequently encounter challenges that hinder their academic success.

Figure 2

Results in Bachelor level in Science Education (2023/24)



Note. Adapted from the statistics provided by Office of the Controller of Examinations, Balkhu (OCOE, 2023)

The multifaceted nature of academic achievement is influenced by a confluence of psychological, socio-economic, and environmental factors, each contributing to the unique learning dynamics experienced by students (Ali et al., 2013). This complexity necessitates a critical examination of the educational landscape, especially considering the shift in assessment practices mandated by the Curriculum Development Center (CDC). The recent transition from a percentage evaluation system to a letter grading system underscores the need for effective assessment practices that can better reflect students’ learning and achievement throughout their educational journey.

Despite the introduction of various assessment tools and methods, disparities in academic performance persist, as evidenced by the National Assessment of Students’ Assessment (NASA) studies. These studies indicate that students from different socio-economic backgrounds face varying levels of academic achievement, emphasizing the necessity for educational reforms aimed at equity (Khanal et al., 2022). In this context, innovative instructional methods, such as concept mapping, have the potential to enhance student engagement and comprehension, addressing the gaps identified in traditional teaching methods.

This study seeks to evaluate the effectiveness of the concept mapping method in enhancing academic achievement in higher-level science education. It focuses on how concept mapping can foster deeper learning and help students establish meaningful connections between scientific concepts. Through this study, the research aims to provide valuable perspectives on teaching strategies that can more effectively meet the diverse learning needs of students in Nepal.

Why am I Interested to Undertake this Study?

As a teacher, I have observed that teaching and learning science is a common problem in public schools in Nepal. In Nepalese schools, learning is often viewed as most effective in a classroom with complete silence, without any discussion, collaboration, or student engagement. Classroom discussions are seldom encouraged by the science teachers. Students are expected to passively receive the content knowledge imparted by the teacher (Shrestha, 2016). As a result, the low levels of science achievement among students are a result of the highly deductive and teacher-centered pedagogical method used in Nepal's public schools to teach and learn science at the basic level (Acharya, 2016). Shrestha (2016) claimed that active learning is preferable to passive learning for students. Teaching should stimulate students to think, feel, and engage, fostering their learning. In this approach, the teacher serves as a facilitator, with students actively participating in their own educational journey.

Moreover, a teacher-centered approach does not adequately foster student conversation, discussion, and thinking in the classroom. In the classroom, students are placed in neat, tidy rows. Students feel monotonous when science is taught using a dogmatic approach, which compels them to memorize the steps. This raises questions about the effectiveness of current science instruction at the B.Ed. level. How well do B.Ed. students understand science? How effective is classroom comprehension?

These reflections sparked interest in exploring how concept mapping-based science instruction could promote meaningful learning for B.Ed.-level students. Also, I had previously conducted a small-scale study in selected schools in the Kathmandu Valley, exploring the effect of concept mapping on the academic achievement of secondary-level science students. The study yielded promising results, with students demonstrating deeper understanding, increased engagement, and improved retention. Motivated by these results, I decided to undertake a more thorough study, focusing on the impact of concept mapping method on the academic achievement of bachelor's level science students. This research was conducted across education campuses in the Kathmandu and Bhaktapur districts, exploring various aspects of concept mapping-based science instruction as utilized by both teachers and students.

Concept mapping offers a structured and effective method for instruction and acquisition of physics at the bachelor level of science education by emphasizing the organization of knowledge, helping students connect concepts meaningfully, and enhancing comprehension and retention. Unlike traditional laboratory methods, which can be rigid and procedural, concept mapping encourages active participation and a more profound comprehension of the subject matter. Research suggests that concept mapping promotes meaningful learning by allowing students to visualize connections between concepts, facilitating better understanding and retention (Novak, 1990a), and supporting the development of critical thinking and problem-solving abilities. Grounded in constructivism, concept mapping aligns with the proactive involvement of learners in constructing knowledge through activities and engagements, enhancing the cognitive processes associated with learning.

By comparing concept mapping with traditional laboratory methods, it becomes evident that concept mapping provides a more interactive and student-centered learning experience. This approach not only improves students' conceptual understanding but also fosters a more engaging and collaborative learning environment. Concept mapping thus emerges as a superior method for teaching physics at the bachelor level of science education. Implementing concept mapping methodologies in B.Ed. level science classrooms could significantly enhance student achievement and retention, addressing the shortcomings of traditional teacher-centered approaches and promoting a deeper, more meaningful understanding of science.

Statement of the Problem

In Nepal, the predominant reliance on conventional teaching methods in physics education resulted in persistently low academic performance among students, despite numerous efforts to enhance learning outcomes. The traditional, teacher-centered approach, which emphasized rote memorization and passive learning, failed to foster meaningful understanding. As Shrestha (2016) highlighted that students learned best when they were active participants, yet in Nepal, most teachers continued to rely on passive, lecture-based instruction, which proved insufficient for promoting meaningful learning. This approach limited student engagement, critical thinking, and troubleshooting abilities, resulting in poor performance in both school-level and higher education physics programs.

The Office of the Controller of Examinations (OCOE, 2023) of Nepal reported that failure rates in the four-year B.Ed. science program remained notably high, especially in physics. Although there were some improvements over time, the majority of students still struggled to successfully complete the program, indicating that the existing teaching methods did not adequately address the learning needs of physics students. Despite these challenges, few studies had explored alternative instructional methods, such as active learning strategies, to address the issues in physics education in Nepal.

The existing literature highlighted the importance of active learning strategies, especially within the framework of Ausubel's Theory of Meaningful Learning. This theory suggested that meaningful learning happens when new information is successfully connected to students' existing knowledge. Novak (1990a) and (Novak & Gowin, 1984) emphasized that concept maps were powerful tools for facilitating this integration, thereby enhancing student engagement and comprehension. Additionally, Constructivist Learning Theory, as described by (Krahenbuhl, 2016), suggested that knowledge was constructed through social interaction and prior experiences, challenging the static nature of traditional learning environments.

Empirical studies demonstrated that concept mapping improved student comprehension, retention, and engagement, particularly in complex subjects like physics. For instance, Pankratius (1990) and Bascones et al. (1985) showed that concept mapping significantly enhanced problem-solving skills among physics students. Similarly, recent empirical studies by Ugwumba (2020) and Aluge et al. (2024) in physics demonstrated that the concept mapping method improved the academic achievement of science students. However, despite these proven benefits, the use of concept mapping method in Nepalese science education remained largely unexplored. While numerous studies on effect of concept mapping method in teaching and learning had been conducted internationally, its exploration within Nepalese educational contexts was limited.

In the Nepalese context, existing studies focused on different applications of concept mapping. Pokharel (2009) explored its importance in social research, while Burke et al. (2024) demonstrated its utility in participatory studies. However, there was a noticeable gap in research specifically investigating the effect of concept mapping on science education, particularly in physics. This lack of focused studies highlighted the urgent need for targeted research to explore the effective integration of concept mapping into higher-level science teaching, especially in Bachelor-level science education programs.

This study aimed to fill this gap by exploring the effect of the concept mapping method on students' academic achievement in science education at the higher level. It sought to explore its potential to foster meaningful learning, improve student engagement, and bridge the disconnect between teaching and learning strategies in Nepalese classrooms. To improve educational outcomes and encourage active engagement in science education, this study integrated concept mapping with Ausubel's Theory of Meaningful Learning and Social Constructivist Learning Theory.

Objectives of the Study

The study focuses on the following objectives;

- To compare the mean achievement score of students in physics taught by concept mapping method and conventional method.
- To investigate the effectiveness of concept mapping method on students' achievement at different cognitive levels in physics against the conventional method.

- To explore effective learning strategies used by students in the concept mapping method.
- To identify the opportunities perceived by teachers and students when using concept mapping method.
- To identify the challenges encountered by teachers and students in teaching and learning while using concept mapping method.

Research Hypothesis

There is significant difference in mean achievement of science education students taught by concept mapping method and conventional methods.

$H_a : \mu_1 \neq \mu_2$, where μ_1 and μ_2 are mean achievement in science education students by concept mapping method and conventional methods respectively

Research Questions

The research questions which underpin the study are as follows:

1. What is the achievement score of students in physics by teaching concept mapping and conventional method?
2. Does concept mapping method improve students' achievement in physics across different cognitive levels?
3. Is there any significant difference in achievement between male and female students, at various cognitive levels, when taught using the concept mapping method versus conventional method?
4. How do students learn effectively in concept mapping method?
5. What are the opportunities perceived by teachers and students when using concept mapping?
6. What are the challenges encountered by teachers and students when using concept mapping?

7. How can we resolve the challenges and promote the opportunities while applying concept mapping method of teaching and learning?

Rationale of the Study

The concept mapping teaching method differs from conventional methods by encouraging active engagement and visual organization of knowledge, fostering deeper cognitive engagement, critical thinking, and problem-solving. Unlike passive learning through lectures and memorization, concept mapping helps students understand the relationships between concepts, enhancing their grasp of complex topics.

Physics, as an intellectually stimulating field, offers a unique opportunity to test concept mapping in our culture. This research aims to improve the teaching and learning of physics, enabling students to better understand phenomena compared to traditional methods. For instance, using a concept map to connect voltage, current, and resistance in Ohm’s Law helps students see these relationships and apply them in real-world contexts.

Concept mapping has proven effective in improving cognitive development, long-term retention, problem-solving, and metacognition. It promotes collaboration and reflection, making it more efficient method than conventional methods in learning physics and other sciences. This study supports the application of concept mapping to enhance teaching methods and improve students' cognitive development, particularly in physics. It aims to investigate the possible advantages of concept mapping in boosting student achievement and learning results.

Delimitation of the Study

Taking into account various limitations, this study was constained by the type and number of samples, the subject matter, the time frame of the experiment, and the resources available. The study focused on bachelor-level science education students (particularly in physics) from Tribhuvan University's constituent campuses in Kathmandu and Bhaktapur districts. One group was designated as the experimental group, while the other served as the control group.

Second, the teaching content in this study was limited to electrostatic and direct current circuits, as specified in the curriculum of the second year of a Bachelor's course in Physics in science education. Furthermore, the content was limited to the cognitive domain (knowledge, understanding, application, and higher ability as specified in the specification grid of the physics curriculum at the bachelor level in science education).

Similarly, with regard to resources and time, the duration of the experiment was limited to forty-five periods as specified in the curriculum. Moreover, method was delimited into the constructivism paradigm. This study was limited to the application of Ausubel's Theory of Human Cognitive Learning and Social Constructivist Learning Theory for analysis.

Summary

This study examines the effect of concept mapping on transforming science education landscape at the higher education level in Nepal. Science education at this level faces numerous challenges, including the predominance of traditional teaching methods that emphasize rote memorization, limited opportunities for interactive and hands-on learning, and assessment practices that often fail to capture deeper understanding. These challenges can result in disengagement and hinder students from making meaningful connections between scientific concepts. Concept mapping provides a promising solution to these challenges by enabling students to visually structure and connect concepts, promoting a deeper and more engaged learning experience.

The study explores how concept mapping affects student engagement, critical thinking, and academic achievement in science, with a particular focus on physics. It aims to identify how this method can be effectively integrated into bachelor-level science education to promote deeper learning, enhance academic performance, and increase student participation. By moving away from passive learning and encouraging students to actively construct knowledge, concept mapping fosters a more student-centered and dynamic learning environment. Ultimately, the research aims to provide valuable perspectives on how concept mapping can enhance the quality of higher education science instruction in Nepal, aligning teaching strategies with the evolving needs of contemporary education and supporting long-term, meaningful learning experiences.

Operational Definition of Terms

Concept: is the smallest unit of cognition, representing a fundamental idea or principle that can be defined, categorized, and connected through concept maps to enhance understanding and application.

Concept maps - are visual depictions of knowledge, consisting of a hierarchy of concepts and their relationships, connected through relevant ideas.

Concept Mapping - is a hierarchical diagrammatic tool that illustrates a set of concept meanings within a framework of propositions, showing the connections between concepts, including their cross-linkages and manifestations.

Concept mapping method - is a structured method that offers a clear graphical representation of ideas and concepts and their relationships, focusing on a specific topic or construct of interest.

Conventional teaching methods - are regular based teaching methods such as lectures, talks, demonstrations, and laboratory experiments.

Effectiveness - is the extent to which something successfully achieves its intended outcome, both in cognitive and non-cognitive aspects.

Science Education – Science education involves teaching and learning science for school children, college students, and the general public, encompassing three broad areas of teaching: content knowledge, pedagogical knowledge, psychological knowledge, and social sciences.

Physics education - is a subfield of scientific education that focuses on the teaching and learning of physics at both school and university levels, along with the training and development of physics teachers and promoting public understanding of physics.

Collaborative - Group learning using concept mapping to explore and understand physics concepts together.

Cooperative - Structured group work with assigned roles, facilitated by concept mapping to achieve learning goals in physics.

Misconceptions - Incorrect physics concepts identified and corrected through concept mapping.

Errors - Specific mistakes in physics learning targeted for correction using concept mapping.

Chapter II

Review of Related Literature

Introduction

The literature review synthesizes studies related to the research issue, providing a framework to assess the value of the research and identify gaps in previous studies (Anderson et al., 1998; Creswell & Creswell, 2017).

The researcher examined available literature on the effect of concept mapping in teaching and learning, emphasizing accessible sources. The review covers theoretical, conceptual, and empirical perspectives, along with a theoretical and conceptual framework and the research implications. It explores prior research on concept mapping's effectiveness in science education, aiming to establish a complete understanding of its impact on student progress.

Theoretical Review of Literature

The theoretical literature review serves as a crucial foundation for any research, especially in a Ph.D. dissertation, as it establishes the scholarly framework that supports the study. It provides a guiding framework that acquaints the researcher with existing knowledge, theories, and models while also highlighting gaps in the literature that the study seeks to fill. By reviewing and synthesizing relevant theoretical perspectives, the researcher can position their work within a broader academic discourse, ensuring that the study is anchored in established knowledge while contributing new insights. Furthermore, this theoretical grounding is essential for substantiating the research findings, as it offers a lens through which data can be interpreted, analyzed, and understood. It also allows the researcher to demonstrate how their study aligns with, diverges from, or expands upon previous work. By critically engaging with the theoretical literature, the researcher strengthens the credibility of their research, providing a strong intellectual foundation for the research questions, methodology, and analysis. In this way, the theoretical review not only justifies the study's significance but also connects it to the ongoing scholarly conversation in the field. The researcher utilized Ausubel's Theory of Human Cognitive Learning, commonly referred to as the Theory of Meaningful Learning, along with Constructivist Learning Theory as the theoretical framework.

Ausubel’s Theory of Meaningful Learning

In the theoretical review of literature, Ausubel's Meaningful Learning Theory plays a key role in understanding how students acquire knowledge by connecting new information to prior cognitive structures. Ausubel (1968) emphasized that meaningful learning happens when new concepts are substantively linked to what learners already know. This highlights the importance of prior knowledge, known as "subsumers," which serve as a foundation for integrating new information. Cognitive structure, according to (Ausubel, 2012), refers to the total knowledge stored in a person's memory, and meaningful learning is demonstrated when new concepts become part of this structure.

The theory highlights that the organization, clarity, and quality of a learner's prior knowledge are fundamental in achieving meaningful learning (Ausubel, 1967). When students can effectively relate new ideas, symbols, or propositions to their cognitive structure, they experience a deeper, conscious understanding of the material (Adriana & Jeanneth, 2010). This process of linking prior knowledge to new information is central to fostering meaningful learning, which Ausubel advocated through expository and deductive teaching methods (Safdar et al., 2012).

Ausubel's theory aligns well with the concept mapping teaching method, which serves as a visual and organizational tool to help learners connect newly introduced concepts with prior knowledge. In teaching topics like electricity in physics, concept mapping can be used to guide students through structured steps based on Ausubel's framework, allowing them not only to acquire new knowledge but also to actively engage with and expand their understanding. Through this method, learners achieve a deeper level of comprehension by creating, refining, and expanding their cognitive structures.

Concept Mapping and Ausubel’s Meaningful Learning Theory

Ausubel’s Meaningful Learning Theory emphasizes the significance of connecting new information to a learner’s existing cognitive structures to promote deep and meaningful learning. This principle aligns seamlessly with the concept mapping teaching method, which serves as a visual and organizational tool, helping learners establish connections between newly introduced concepts and their prior knowledge (Novak & Gowin, 1984). In the context of teaching electricity, concept mapping can be effectively employed to facilitate meaningful learning by guiding students through structured steps that correspond to Ausubel's theoretical framework (Ausubel, 1968). Through this method, students not only acquire new knowledge but also actively engage with the material by creating, refining, and expanding their understanding, thereby achieving a deeper level of comprehension (Novak, 1998).

According to Ausubel’s theory, first advance organizers serve as introductory materials that help learners prepare for new content by activating relevant prior knowledge (Ausubel, 1960a). In this regard, concept mapping behaves as an advance organizer, particularly in subjects like electricity. By presenting foundational concepts such as charge, electric field, potential energy and dc circuits through concept maps, subject teachers provide a cognitive framework that students can utilize throughout the lesson. For example, displaying a simple concept map that includes core ideas like positive charge, negative charge, and Coulomb’s law enables students to organize their pre-existing knowledge and connect it to new information. This process not only reduces cognitive overload but also fosters a structured approach to learning (Ausubel, 1968; Novak, 2010).

Another central tenet of Ausubel’s Meaningful Learning Theory is the idea that new knowledge is best learned when it is connected to relevant, pre-existing concepts within the cognitive structure of the learner (Ausubel, 1968). The concept mapping teaching method directly facilitates this process by encouraging students to make connections between new concepts and their prior understanding. In teaching electrostatics, students can progressively expand their concept maps by integrating new material, such as electric force, Gauss’s law, and electric field lines, with foundational concepts like Coulomb’s law. By making these connections explicit, students achieve a deeper and more meaningful grasp of the material, reinforcing their understanding of the subject matter (Arends, 2011; Novak, 2010).

Furthermore, Ausubel emphasizes the hierarchical nature of knowledge acquisition, where general concepts are learned before delving into specific details (Ausubel, 1963). The concept mapping teaching method naturally reflects this by organizing ideas in a top-down, hierarchical manner (Novak & Gowin, 1984). In the context of electricity, concepts such as electric charge, Coulomb’s law and dc circuits are positioned at the top of the map, while specific ideas like equipotential surfaces and electric dipoles branch out beneath them. This hierarchical structure mirrors Ausubel’s cognitive model and aids students in comprehending how broader ideas govern specific details, thus reinforcing logical knowledge acquisition (Ausubel, 1968).

Additionally, progressive differentiation is a key concept in Ausubel’s framework, referring to the gradual acquisition of increasingly detailed knowledge over time (Ausubel, 1968). Concept mapping supports this cognitive process by allowing students to continuously add new branches and sub-concepts to their maps (Novak, 2010). In electrostatics, students might begin with the general concept of an electric field and progressively differentiate it by incorporating specific aspects like electric field lines and Gauss’s law. As they expand their maps, students refine their understanding, reflecting the cognitive elaboration process (Ausubel, 1968).

Integrative reconciliation, another significant component of Ausubel’s theory, involves learners integrating new ideas with existing knowledge to resolve cognitive conflicts (Ausubel, 1968). The concept mapping teaching method supports this by requiring students to revise and expand their maps as they encounter more complex ideas (Novak & Gowin, 1984). For instance, students can visualize the relationship between electric potential and electric force through concept maps that illustrate connections among electric fields, potential energy, and forces. This visual mapping allows students to resolve conflicts, leading to a more coherent understanding of the material (Novak, 1984).

Moreover, Ausubel posits that meaningful learning results in better retention and transfer of knowledge (Ausubel, 1968). Concept mapping enhances retention by encouraging students to revisit and refine their understanding of concepts regularly (Novak, 2010). In the context of electricity topics, students can continually update their maps with new information, reinforcing the relationships among key concepts, which ultimately improves memory retention.

Finally, Ausubel’s theory promotes active learning through the organization of concepts (Ausubel, 2012). The concept mapping teaching method directly encourages this by engaging students in the creation and refinement of their own concept maps (Novak, 2010). In the study of electricity, students actively participate in organizing their understanding of concepts like electric force, Gauss’s law, and ohm’s law which promotes deeper cognitive processing, as emphasized by Ausubel (1963). Furthermore, by continuously refining their maps, students engage in meaningful learning, internalizing the material while simultaneously developing critical thinking skills (Novak, 1983).

In this study, researcher aimed to validate whether concept mapping, which fosters the integration of new information into existing cognitive structures, led to higher academic performance compared to conventional methods. This method directly supports Ausubel’s Meaningful Learning Theory, which posits that learning is most efficient when new concepts are anchored to prior knowledge. Concept mapping facilitated this by helping students organize and visualize relationships between ideas, thereby enhancing understanding and retention. The alignment with Ausubel's theory was evident in how concept mapping promoted organized, relatable content, improving learning outcomes.

Moreover, by identifying opportunities and challenges in utilizing concept mapping, the study provided insights into adapting teaching strategies to better support meaningful learning. This adaptability is essential, as it ensures that teaching methods address barriers to implementation and align with students' cognitive structures and readiness to learn. As a result, the application of concept mapping in my research contributed to a more flexible and student-centered approach, ultimately guiding improvements in instructional practices to support meaningful learning, as Ausubel advocated.

Constructivist learning theory

Use of Vygotsky's Social Constructivism in Learning Electricity through Concept Mapping

Constructivist learning theory emphasizes that students actively construct knowledge through experiences rather than passively absorbing information (Krahenbuhl, 2016). In the context of teaching electrostatics and DC circuits, concept mapping proves to be an effective tool for helping students visualize and structure their understanding of complex electrical concepts, such as voltage, current, and resistance. By engaging with concept maps, students are encouraged to link new knowledge with prior understanding, leading to deeper grasp and retention of electrical principles (Harpaz et al., 2004).

Social constructivism, founded by Lev Vygotsky, extends this learning framework by asserting that individuals create knowledge through social and cultural interactions (Schreiber & Valle, 2013; Thomas et al., 2014; Vygotsky, 1980). Vygotsky's theory highlights the importance of social interaction in learning, especially in collaborative environments where students engage in small group or pair work to discuss, negotiate, and jointly construct knowledge (Johnson & Bradbury, 2015). In this context, teachers act as facilitators, guiding discussions and fostering environments where students can learn from one another (Powell & Kalina, 2009). According to Prawat (1992), meaningful conversation and interpersonal interaction are central to the teaching and learning process, particularly when focusing on students' comprehension of complex subjects like electricity.

In applying social constructivism to teaching electrostatics and DC circuits, concept mapping becomes a vital tool for group-based learning. Through concept mapping, by engaging students, they can actively build and refine their understanding of key concepts such as electric charge, electric field lines, Ohm's Law, and circuit behavior. For instance, discussing and mapping the differences between series and parallel circuits in small groups allows students to correct mistakes and solidify their understanding through peer interaction. This engagement in group reinforces the social nature of knowledge construction, as students exchange ideas and build a shared understanding of electrical concepts (Gredler, 2001).

Additionally, concept mapping allows students to connect their learning with real-world applications, further enhancing motivation and engagement (Almulla & Alamri, 2021). By visualizing how circuit principles apply to everyday electrical devices, students see the relevance of their learning, which enhances their grasp of theoretical concepts. Teachers can also use concept maps to assess students' prior knowledge and identify misconceptions, which allows for more targeted instruction (Krahenbuhl, 2016).

The iterative nature of concept mapping supports Vygotsky's Zone of Proximal Development (ZPD), where students move from tasks they can perform with assistance to tasks they can perform independently (Schreiber & Valle, 2013; Vygotsky, 1980). As students develop and refine their concept maps, they gradually internalize electrical concepts. Initially, they may need guidance to understand abstract principles, but as they continue revising their maps, they develop the ability to solve problems and explain concepts like Kirchhoff's Laws or electric potential on their own (Sarker, 2019). This scaffolding, as described by (Wood et al., 1976), enables learners to perform beyond their current level of understanding and gradually gain mastery over the subject.

Moreover, the process of creating and refining concept maps promotes the progressive differentiation of knowledge, where students start with general concepts (e.g., electric charge) and gradually incorporate more specific sub-concepts (e.g., current, voltage, resistance). This hierarchical organization of information helps students understand overarching principles governing electrical circuits (Aljohani, 2017). As they continue to add branches to their maps, students engage in cognitive elaboration, refining their understanding of both basic and complex electrical phenomena.

The concept mapping method also facilitates integrative reconciliation by helping students resolve cognitive conflicts between new information and prior knowledge (Garabet & Miron, 2010). For example, when students visualize the relationships among current, voltage, and resistance in a DC circuit, they clarify how these variables interact according to Ohm's Law, reinforcing the connections they have made between theoretical and practical knowledge.

Concept mapping supports the active, group-based learning process central to Vygotsky’s social constructivism. By engaging in discussions and working together on maps, students not only deepen their understanding of electrostatics and DC circuits but also learn to apply these concepts in real-world contexts. This approach exemplifies the constructivist view of learning as an active, social process where students construct knowledge through meaningful interactions and experiences (Schreiber & Valle, 2013; Vygotsky, 1980).The continuous refinement of concept maps promotes both the retention of electrical concepts and the ability to transfer knowledge to different contexts, further emphasizing the value of concept mapping as a instructional resource in science education.

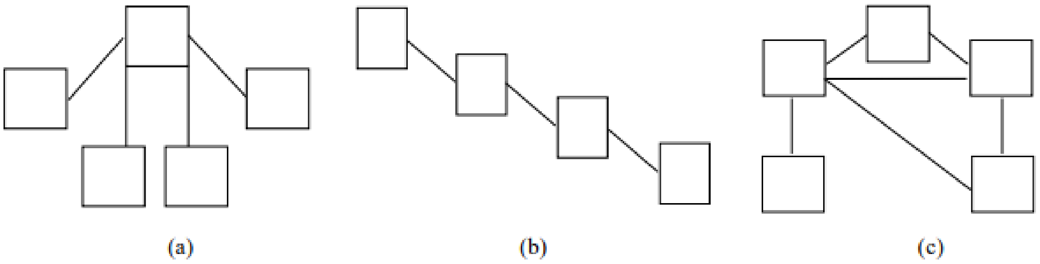
Conceptual Review of Literature

The development of concept maps by Novak's research group in 1972 marked a significant shift in educational practices, particularly in tracking and understanding children's scientific knowledge (Novak & Musonda, 1992). This innovation stemmed from the need to move beyond traditional interview methods, which failed to capture the full extent of children's conceptual understanding. Concept mapping, influenced by Ausubel's theory of cognitive psychology, offered a more structured way to visualize how new ideas are integrated into existing cognitive structures (Ausubel, 1968). Through the introduction of a visual and hierarchical method, it made abstract thinking more accessible and measurable, representing a key advancement in assessing cognitive development. Researchers were now able to trace how new concepts were integrated into preexisting knowledge.

Following its introduction, concept maps evolved to become not only a tool for tracking knowledge but also a structured framework for learning. Components such as concepts, propositions, hierarchies, and cross-links enabled educators and learners to systematically map relationships between ideas. These elements enhanced the learning process by promoting a deeper, more interconnected understanding of subjects (Novak & Canas, 2006a). The subsequent development of various concept map formats, including the spoke, chain, and net structures (Kinchin, 2000), highlighted the tool's versatility and adaptability to different educational contexts. These structures allowed educators to adjust to different levels of complexity in learning, suggesting that concept maps could adapt to diverse educational contexts and needs.

Figure 3

Types of concept map



Note. Adapted Concept Map Types: (a) spoke, (b) chain, (c) net by Kinchin (2000)

Empirical evidence over the years has confirmed the pedagogical value of concept mapping. Studies have consistently shown that concept maps promote metacognitive thinking, comprehension, and critical thinking (Chabeli, 2010). For example, in physics education, Stoica et al. (2011) found that students used concept maps to visualize and understand abstract ideas, such as electric charge and circuit behavior. These findings suggest that concept maps help learners grasp not only specific content but also transform their approach to complex subjects. By structuring their thoughts, students can make difficult material more manageable and learning more efficient.

In addition to improving comprehension, concept maps have shown psychological benefits, notably in reducing learning anxiety and improving attitudes toward challenging subjects (Swan, 2003). In physics, where students often struggle to link theoretical concepts with practical applications, concept maps provide a way to clarify these connections. Research by Morsi et al. (2007) highlighted improved academic performance due to this clarity, indicating that concept maps enhance retention and engagement with the material. This evidence suggests that concept maps promote not only better understanding but also a more confident, motivated approach to learning.

Concept maps also play a diagnostic role by helping to identify mistakes and knowledge gaps (Thompson & Logue, 2006). Their visual format enables both students and educators to detect inconsistencies in understanding early. This diagnostic function extends to curriculum design, as McDaniel et al. (2005) demonstrated, showing that concept maps can assist curriculum developers in integrating new competencies with foundational knowledge. This indicates that concept maps are not only learning tools but also valuable resources for educational planning and improvement.

However, the implementation of concept maps is not without challenges. (Novak & Gowin, 1984) pointed out the learning curve that both students and educators face when adapting to the method. Incorrect connections between concepts, if not properly guided, can lead to misunderstandings. These challenges suggest that while concept maps have the potential to significantly enhance education, their success depends on proper implementation and guidance. This points to a need for structured support and further professional development to maximize their effectiveness.

Empirical Review of Literature

Concept Mapping for Meaningful Learning

Concept maps have been strongly endorsed for both affective and cognitive gains by Novak (1984). Between 1985 and 1987, Novak himself instructed upper elementary and secondary school students on concept mapping, which sparked numerous further studies and increased the popularity of this tool in educational settings. Building on this foundation, Bascones et al. (1985) sought to investigate the impact of concept mapping on students' abilities to solve physics problems. Their study, grounded in Ausubel's theory of meaningful learning, strongly supported the use of concept maps in instruction. In a similar vein, Mikulecky et al. (1989) emphasized that concept maps must be taught in a manner that allows students to independently repeat the process for them to be effective learning aids. They stressed that for concept maps to support learning experiences, students need to fully comprehend their use, or the benefits may be lost on untrained individuals.

Complementing these findings, Carey and Shavelson (1989) demonstrated that concept maps tap into important aspects of students' knowledge structures and enhance meaningful learning. Furthermore, Cullen (1990) argued that concept mapping was an effective method for instructing abstract concepts in college freshmen chemistry, helping to overcome misunderstandings and misconceptions among students. Continuing this exploration, Novak (1990a) discussed the genesis and development of concept mapping as an effective method for science education. In a similar vein, Heinze-Fry and Novak (1990) investigated its effectiveness in enhancing meaningful learning among college biology students over three instructional units, showing how concept mapping helped address mistakes in science education.

Moreover, Okebukola and Jegede (1990) investigated the effectiveness of concept mapping in teaching genetics and ecology, finding that the experimental group performed better than the control group in genetics. However, no substantial difference was found in ecology, attributed to chance factors. Expanding on the role of concept mapping, Novak (1990b) compared concept maps with Vee diagrams, highlighting their potential as meta-cognitive tools for facilitating meaningful learning. This study reviewed the psychological and epistemological foundations of these tools and discussed the challenges faced in moving from rote learning to meaningful learning strategies. In fact, the data from qualitative and quantitative research supported the value of these meta-cognitive tools for both cognitive and affective gains.

In a related study, Willerman and Mac Harg (1991) explored concept maps as knowledge-organizing tools for eighth-grade science students, finding notable differences between the control and experimental groups. The finding indicated that concept maps were effective advance organizers for structuring information. Conversely, Briscoe and LaMaster (1991) reported that many students believed memorizing textbook material was sufficient and found concept mapping challenging. They noted that students often struggled with creating concept maps due to a lack of necessary knowledge frameworks and would give up easily when frustrated. Further elucidating the benefits of concept mapping, Crandell et al. (1996) described it as a visual method for classifying concepts to illustrate their interrelations. Thus, concept maps helped show hierarchical links, promoting meaningful learning.

In addition, Regis et al. (1996) highlighted concept maps as reflective tools for improving teaching and learning in chemistry. They were employed to address shifts in learning processes and perceptions of scientific knowledge. Moreover, Gold and Coaffee (1998) evaluated concept mapping's application in urban geography education, discussing its effectiveness through student feedback and course evaluations. Their study underscored concept mapping's promise for teaching complex concepts. Similarly, Wilkes et al. (1999) discovered that integrating concept mapping into nursing education improved students' understanding of how scientific principles related to their field, enhancing their ability to educate patients.

Continuing this line of inquiry, Ritchie and Volkl (2000) compared concept mapping and lab activities as learning techniques. They discovered that students who created concept maps before lab activities had better long-term retention compared to those who created maps afterward. Nevertheless, group and individual work did not significantly differ in effectiveness. In another study, Sungur et al. (2001) examined the impact of conceptual shift materials and concept mapping on students' comprehension of the human circulatory system, finding that the combination of these methods positively impacted students' conceptual understanding, with the experimental group outperforming the control group.

Further investigation by Otis (2001) revealed that concept maps, while useful for enhancing meaningful learning, were found inconsistent in their complexity, affecting their assessment utility. In addition, Zieneddine and Abd-El-Khalick (2001) emphasized that concept maps, when combined with teaching strategies aimed at conceptual change, improved students' performance on concept tests, despite the lack of a statistically significant difference from the control group. In the same line, Canas et al. (2003) reviewed studies showing that concept mapping benefits less proficient learners by promoting an active and organized approach to learning. Moreover, Gahr (2003) highlighted how concept mapping connects general and specific concepts, improving the organization and monitoring of student knowledge in chemistry labs.

Finally, Novak and Canas (2006b) characterized concept maps as powerful tools for structuring and displaying information, noting their benefits for writing, research, administration, and evaluation. They emphasized that, although concept maps initially appear simple, they can become complex and insightful when used effectively. Supporting this notion, Voltaire (2009) demonstrated concept mapping's role as both an advance organizer and an assessment tool within the Ausubel-Novak-Gowin framework for meaningful learning. In recent studies, Stoica et al. (2011) showed that concept maps are a modern educational strategy for achieving excellence in learning, particularly in physics. Furthermore, Ahlberg (2013) reviewed over 20 years of research on concept mapping and mind mapping, concluding that concept mapping is a powerful method for enhancing learning, critical thinking, teaching, and research.

Likewise, Kilic and Cakmak (2013) proposed concept maps as a dynamic and student-centered instructional strategy for chemistry education. Lastly, Soika and Reiska (2014) explored the application of concept mapping as an assessment method, finding it effective for visualizing students' conceptual achievements. In addition, Alhomaidan (2015) demonstrated that concept mapping significantly improved college-level students' learning outcomes in comparison to traditional methods, highlighting its continued relevance and effectiveness in education.

These studies demonstrated that concept mapping is widely supported for enhancing cognitive and affective outcomes in education. From its early use to recent developments, concept mapping has been validated as an effective tool for improving students' understanding across various subjects, including science and mathematics. Moreover, it has proved beneficial for structuring information, addressing misconceptions, and supporting meaningful learning. However, some studies also noted challenges in its application and effectiveness, highlighting the need for careful implementation and support. Concept mapping has remained a valuable educational strategy for fostering deeper comprehension and better organization of knowledge.

Studies Supporting Concept Mapping in Science

Among secondary school physics students, Pankratius (1990) examined the effect of concept mapping on problem-solving skills. His study included students from six intact secondary school physics classes; notably, four of these classes received a six-week period of concept mapping instruction prior to the study unit, while the remaining two served as control groups that received conventional instruction. The results indicated that concept mapping, when applied before, during, and after teaching, led to higher performance, as evidenced by improved post-test scores. This foundational study underscores the significance of concept mapping in enhancing educational outcomes, providing a basis for further research in diverse scientific disciplines. Moreover, this lays the groundwork for understanding how concept mapping can be successfully incorporated into various teaching methodologies.

Building on this, Ross and Munby (1991) explored senior high school students' conceptual understanding of acids and bases, thereby expanding on the effectiveness of concept mapping revealed by Pankratius (1990). They developed a concept map based on the curriculum and used it to design an exam with multiple-choice questions and clinical interviews. Their research revealed that students held unique concepts that often diverged from the recommended curriculum, retaining everyday concepts more strongly than scientific ones. Thus, this finding not only highlighted the value of concept mapping in uncovering gaps in students' understanding but also its impact on conceptual learning, suggesting that the method can bridge the divide between students’ existing knowledge and the scientific concepts they need to grasp.

In addition, Hand and Treagust (1991) conducted a study comparing constructivist and non-constructivist approaches for teaching acids and bases to tenth-grade students, which further supports the positive implications of concept mapping in science education. Their findings showed that a constructivist approach significantly improved students' knowledge and learning achievement. Consequently, the constructivist strategy, particularly when utilizing concept maps, proved highly effective in aiding students' understanding and problem-solving abilities, further supporting the notion that concept mapping is a valuable tool for promoting deeper comprehension.

Similarly, in a related study, Barenholz and Tamir (1992) explored the application of concept mapping in microbiological courses for tenth and eleventh graders. They demonstrated that concept mapping resulted in improved skills in map creation and deeper learning. Consequently, both students and teachers appreciated the cognitive benefits of concept mapping, which was well-received in instructional design. This positive feedback aligns with previous studies, underscoring the consistent advantages of incorporating concept maps into science education and encouraging further exploration of this methodology.

Furthering this discourse, Cavallo and Schafer (1994) investigated the meaningful learning that emerges from using concept maps, specifically in the context of tenth graders studying meiosis. The study indicated that students' prior knowledge, rather than the instructional approach itself, played a crucial role in achieving meaningful comprehension. Here, concept maps were valuable for exploring and documenting students' conceptual frameworks, reinforcing the idea that these tools enhance learning by linking new information to prior knowledge.

Building on these insights, Esiobu and Soyibo (1995) investigated the effectiveness of concept and vee mapping techniques in various learning conditions for tenth-grade students studying ecology and genetics. They found that in each learning modality, the experimental groups using concept and vee mapping outperformed the control groups, demonstrating the versatility and effectiveness of these mapping techniques. Therefore, this study expanded the context in which concept mapping could be applied, illustrating its adaptability to different learning environments and reinforcing its role in promoting student achievement.

In addition to this, Markow and Lonning (1998) investigated the use of concept maps in college chemistry laboratories, focusing on students' perceptions and achievement. Their study compared pre- and post-lab concept maps with traditional essay methods. Despite positive student feedback on the concept maps, achievement tests showed no notable differences between the treatment groups. However, students indicated that concept maps were helpful for grasping the conceptual aspects of chemistry of experiments, indicating that the benefits of concept mapping may extend beyond measurable academic outcomes.

Further research by Sisovic and Bojovic (2000) illustrated the effectiveness of concept maps in conjunction with demonstration experiments, aiding students in applying their understanding of concepts and their interrelations. Their research illustrated the effectiveness of concept maps in linking chemistry and physics concepts, thereby enhancing students' comprehension through systematic instruction. Consequently, this illustrates the capacity of concept mapping to create interdisciplinary connections that further deepen students’ understanding of scientific concepts.

Moreover, Guastello et al. (2000) examined the impact of concept mapping on low-achieving seventh-graders' comprehension of science content. They compared concept mapping with a reading and discussion approach, finding that the concept mapping method led to better performance. This approach helped in developing students’ cognitive schemas and improving their understanding of science, thus highlighting the method's efficacy, particularly for students who may struggle with traditional instructional strategies.

Furthermore, Kharatmal and Nagarjuna (2004) argued for the creation of a genuine set of knowledge organizers, including concept maps, for science instruction.

They identified several issues associated with the concept-mapping approach and emphasized its importance in promoting meaningful learning. By acknowledging both strengths and challenges, this research provides a balanced understanding of concept mapping's role in educational settings, offering pathways for future enhancements.

Continuing this exploration, Sheu (2008) assessed the utilization of concept maps in senior high school ecology courses and compared them with web page-based browsers for accessing information. The study showed that concept map-based interfaces improved search performance and accuracy for all learners, with more pronounced benefits for those engaged in meaningful learning. Thus, this finding further supports the argument that concept mapping can enhance not only comprehension but also research skills, making it a multifaceted educational tool.

Similarly, Pehkonen et al. (2009) highlighted the potential of graphical knowledge representation tools like concept maps in physics education. They noted that Concept Map Tools provided a versatile platform for adapting structures, with positive student feedback on its impact on learning and collaboration. As such, this aligns with the notion that concept mapping fosters an interactive learning environment, encouraging students to engage with content in group with their peers.

Additionally, in a comparison of collaborative concept mapping and collaborative writing, Haugwitz et al. (2010) found that concept mapping was especially advantageous for students with below-median cognitive abilities when working in groups of similar cognitive levels. This finding indicated that concept mapping could be an effective tool for targeted educational strategies, thereby further supporting its role in differentiated instruction.

Furthermore, Nousiainen and Koponen (2010) investigated the structure and content quality of electricity and magnetism concept maps. Their findings underscored the close relationship between structural traits, such as clustering and hierarchy, and the quality of concept maps. This highlights the importance of teaching students how to create effective concept maps, which can significantly enhance their learning experiences and understanding of complex topics.

In a broader context, Rodriguez et al. (2010) reviewed the literature on concept maps in science teaching and discussed their role in promoting conceptual change. They highlighted studies involving joint creation of concept maps in a group and the initial findings on conceptual shift processes, offering valuable insights into how concept mapping can foster transformative learning experiences.

Moreover, Ghani et al. (2016) investigated the use of concept maps for evaluating students' understanding of electrolysis through laboratory activities. The study demonstrated that concept maps served as an effective alternative evaluation method, significantly improving students' knowledge levels and receiving positive feedback from students. This not only reinforces the efficacy of concept mapping in learning environments but also suggests its potential for assessment purposes.

Lastly, in a small-scale study, Gourlay (2018) used concept mapping to assess students' comprehension of particle physics at the A level. The study compared knowledge propositions on students' concept maps with those from the test specification, revealing that while students understood fundamental concepts, some misconceptions about quarks remained. This highlights the need for ongoing refinement of concept mapping techniques to address persistent misunderstanding effectively.

The above studies demonstrated that concept mapping significantly enhances student learning across various subjects and educational levels. Research consistently found that concept mapping improved problem-solving skills, conceptual understanding, and performance in physics, chemistry, and biology. Moreover, the method revealed gaps in students' knowledge and helped address misunderstanding, making it a valuable tool for both teaching and assessment. Additionally, concept mapping was effective in diverse learning environments, including individual, cooperative, and competitive settings, and showed particular benefits for low-achieving students. Despite some challenges, concept mapping proved to be a versatile and impactful educational strategy.

Concept Mapping as an Effective Tool for Achievement in Science

The exploration on the effects of concept mapping on student achievement in science has received significant attention over the years. Snead and Snead (2004) explored these impacts through a quasi-experimental design, finding that while concept mapping did not improve overall science proficiency for all students, it did have a notable positive effect on lower-ability students. This raises an interesting point: concept mapping may be more beneficial for struggling learners, suggesting that its utility might be dependent on student ability. However, the applicability of this finding is constrained by the study's focus on only one grade level (eighth-grade students), and it would be valuable to see if the same effects hold across different educational stages and disciplines.

Building on this, Rao (2004) also found that concept mapping contributed positively to both cognitive development and students' perspectives. His research, like that of Snead and Snead, underscores the method's potential for fostering motivation. Nevertheless, while the cognitive improvements are clear, Rao’s study does not address whether these improvements translate to long-term retention or application of knowledge. This remains an important question for future research.

Similarly, Chandra (2007) reinforced these findings by showing that concept mapping improved not only science achievement but also problem-solving skills, suggesting that it may support higher-order thinking. However, Chandra’s study did not isolate which aspects of concept mapping contributed most to these improvements—whether it was the visual representation of knowledge, the active engagement with the material, or the organization of ideas. Understanding this would help in fine-tuning the application of concept mapping in science classrooms.

Extending this line of inquiry, Ling and Boo (2007) demonstrated that concept mapping as a revision tool could help students achieve higher posttest scores. This adds another dimension to the argument: concept mapping can not only support learning during regular instruction but also improve revision practices. Nonetheless, Ling and Boo's study does not explore whether concept mapping helps students retain information over time, an important factor in assessing the long-term benefits of the method.

In a more focused study on physics education, Karakuyu (2010) reported a positive shift in students' attitudes but found no significant difference in academic performance. This highlights a critical consideration: while concept mapping may enhance engagement and motivation, its direct impact on academic performance is not always clear. Thus, Karakuyu's findings suggest that concept mapping might work better as a motivational tool rather than as an immediate solution for improving test scores.

In support of this, Pardo Fernandez and Montanero (2010) identified concept mapping as a collaborative tool that effectively supported conceptual change among students and teachers in physics education. Their research reinforced the idea that concept mapping does more than enhance knowledge retention—it facilitates deeper cognitive processes, leading to a reconstruction of existing knowledge frameworks. This conceptual change is pivotal in subjects like physics, where complex and abstract ideas often require alternative instructional strategies for better comprehension.

Moreover, Adlaon (2012) found that concept mapping improved proficiency in biology education, aligning with earlier studies on its broader pedagogical benefits. However, the success of concept mapping may be influenced by subject-specific factors, as biology may lend itself more readily to visual representations compared to other subjects, such as abstract physics concepts. This variation across subjects warrants further examination.

In line with these findings, Jagadeesh (2012) demonstrated that concept mapping significantly enhanced academic performance and problem-solving skills. While this study adds to the growing evidence supporting the method’s effectiveness, its design did not entirely control for potential confounding variables, such as student motivation or prior knowledge, which could also have impacted the results.

Additionally, Cheema and Mirza (2013) explored gender dynamics, noting that male students outperformed female students using concept mapping. This finding invites further exploration into whether the method is equally effective for all students or whether certain demographics might benefit more from this teaching strategy. This brings into question whether gender plays a role in the effectiveness of concept mapping in science education, highlighting the need for further investigation.

Similarly, Aziz and Rahman (2014) reaffirmed the positive impacts of concept mapping on science performance but did not delve deeply into how different groups (e.g., gender, age) responded to the method. This lack of specificity calls for more nuanced research that considers individual learner characteristics, rather than applying concept mapping uniformly.

In further research, Ogonnaya et al. (2016) found concept mapping to be more effective than traditional methods for both male and female students, with no notable gender differences. This contrasts with earlier studies suggesting that gender may affect outcomes. Therefore, Ogonnaya’s work provides important insight into the method’s universal applicability across demographics.

Following this, Sakata (2016) demonstrated the method’s success in improving physics achievement, reinforcing the broader applicability of concept mapping. However, Sakata’s study also noted a slight advantage in performance for male students, indicating that while the method is effective, there may be gender-related differences that should be explored further. In light of this, future research should focus on identifying the specific conditions under which concept mapping is most beneficial, including any gender-related factors.

The findings by Luchembe et al. (2017) also strengthened the argument for concept mapping's effectiveness, particularly in improving conceptual understanding in undergraduate physics. By comparing concept mapping with instructional sheets, they demonstrated its superior impact on student learning outcomes. The favorable attitudes reported by students toward the method further emphasize the psychological and cognitive benefits of using visual learning tools to simplify complex topics like circular and rotational motion. This supports earlier studies by showing how concept mapping can drive both affective and cognitive development.

In continuation, Meheux (2017a) and Asubiojo (2018) confirmed the academic advantages of concept mapping in physics, as students in concept mapping-based classrooms outperformed their peers in traditional classrooms. Nevertheless, their studies did not explore how the method impacts students' long-term retention or its effects in classrooms with diverse learner profiles. This suggests that while immediate academic improvements are evident, there may be further benefits, such as fostering deeper, more sustained understanding, that remain underexplored.

Similarly, Doris (2018) confirmed the academic benefits of concept mapping, demonstrating improved performance in physics compared to conventional teaching methods. This consistency across multiple studies shows the method’s robustness as an instructional tool. Additionally, the absence of notable gender disparities in achievement indicates that the effectiveness of concept mapping goes beyond demographic variables, making it an equitable educational strategy.

Finally, Ghorai and Guha (2018) and Sukanya and Shekhar (2019) provided additional evidence supporting the superiority of concept mapping over demonstration strategies in improving physical science learning. Together, their findings consolidate the argument that concept mapping is a powerful tool for improving educational outcomes. However, the consistency of these findings across different science domains remains a topic for further research to confirm its universal applicability.

Ugwumba (2020) similarly demonstrated that concept mapping enhanced students' understanding of waves in physics, again without significant gender differences in performance. This consistency across studies suggests that concept mapping is not only effective but also reliable across various physics topics and student groups. Its effectiveness in addressing difficult concepts like waves, which are often abstract, underscores its value as a strategy for improving conceptual clarity.

Anastasiou et al. (2024) provided a broader perspective through a meta-analysis, showing that concept mapping was particularly beneficial for low-achieving students and effective across different science subjects, including physics, biology, and chemistry. The study’s focus on low- and middle-income countries also highlighted concept mapping's potential as a tool for reducing educational disparities.

This implies that concept mapping might play a key role in global efforts to address inequality in education.

Finally, Aluge et al. (2024) confirmed many of the earlier findings, showing that the Concept Mapping Instructional Strategy (CMIS) significantly improved student achievement in physics, with no significant gender differences. This further validates the method’s versatility and adaptability across diverse student populations, reinforcing its place as a key pedagogical tool in physics education. The cumulative evidence from these studies demonstrates that concept mapping consistently improves both engagement and academic performance, making it a valuable instructional method across various educational contexts.

These studies collectively revealed that concept mapping enhances not only student engagement and attitude but also performance across different educational settings and student demographics. The consistency of findings, regardless of gender or regional context, reinforces its wide applicability. Moreover, its particular effectiveness with low-achieving students and in challenging subjects suggests that concept mapping is an equitable and powerful tool for improving science education globally.

Studies in the Nepalese Context

In the Nepalese context, empirical research on concept mapping is limited, but two notable studies provide valuable insights into its application. Pokharel (2009) explored the importance of concept mapping in social research, especially in theory construction and testing. The study emphasized how concept mapping operates at the conceptual-theoretical level, guiding scientific observations and aiding in the development of theoretical frameworks. While not directly related to physics education, Pokharel's work highlights the capacity of concept mapping in organizing and structuring information, which can be applied to educational contexts. This suggests that concept mapping may not only facilitate learning but also enhance the cognitive processes involved in constructing and testing ideas across various fields.

Similarly, Burke et al. (2024) employed concept mapping in a participatory study exploring adolescent girls' empowerment in Nepal. Although the focus was on social issues rather than physics, the study showcased the utility of concept mapping in identifying and organizing complex social phenomena. This highlights the versatility of concept mapping as a tool for understanding intricate subjects, whether in social research or educational settings. The participatory nature of the study also points to concept mapping's capacity to engage diverse groups, fostering group learning and critical thinking—skills that are equally relevant in science education.

Both studies, though outside the realm of physics education, illustrate the broader applicability of concept mapping in fostering understanding, organizing ideas, and enhancing conceptual clarity. These findings suggest that the method's cognitive and organizational benefits in social research can inform its potential in physics and other scientific disciplines within the Nepalese education system.

Studies Related to Psychological Concepts

Okebukola and Jegede (1989) investigated whether the concept-mapping approach could effectively reduce students' anxiety levels and alter their attitudes toward subjects previously deemed difficult. Their results indicated that students' perceptions of the difficulty and anxiety associated with ecology and genetics—areas traditionally feared in biology—improved as a result of engaging with concept mapping. In light of these findings, Jegede et al. (1990) aimed to determine whether using concept mapping as a metacognitive approach could help alleviate anxiety and enhance biology achievement. To assess the treatment's impact on both anxiety and achievement, they utilized two instruments administered in pre- and post-test formats: The Zuckerman Affect Adjective Checklist and the Biology Achievement Tests. Consequently, the findings supported the hypothesis that concept mapping proved significantly more effective than conventional expository instruction in improving biology learning and reducing student anxiety. Notably, male students experienced a considerable reduction in anxiety.

Expanding on these insights, Chiou (2008) explored whether concept mapping could boost students' learning success and engagement. The study found that concept mapping significantly improved students' learning achievements compared to traditional expository teaching methods. Additionally, most students expressed satisfaction with the concept mapping approach, further emphasizing its positive impact on learning. This reinforces the idea that concept mapping not only addresses psychological barriers but also enhances overall engagement in the learning process.

In a related study, Abdulkarim and Raburu (2013) examined how concept mapping influenced students' attitudes toward physics instruction. They collected data using pre- and post-attitude scales over an eight-week period, during which students received three mechanics sessions each week. The findings revealed a marked disparity in attitudes toward physics between the experimental and control groups, suggesting that concept mapping positively affected students' perceptions of the subject.

This was echoed by Akay et al. (2012), whose study examined the impacts of concept mapping on academic performance and attitudes. This experiment, which included pre-test and post-test control groups, identified that the cognitive support provided by concept maps positively influenced students' success and information retention. Moreover, students demonstrated an optimistic view toward concept maps.

Building on these findings, Luchembe et al. (2017) further analyzed the effectiveness of concept mapping as an instructional method for undergraduate physics students. Comparing concept mapping with instructional sheets for instructing circular and rotational motion, they found that concept mapping was more effective. The study employed pre-tests and post-tests to measure effectiveness, and students' attitudes toward concept mapping were assessed through interviews and questionnaires. Thus, the findings suggested that students held a favorable attitude toward the concept mapping method, further supporting its efficacy in promoting positive educational experiences.

Patriciah et al. (2014) further explored the influence of Experiential Cooperative Concept Mapping on students' motivation to study physics. Utilizing a quasi-experimental Solomon Four Non-equivalent Design of Control Groups, the study identified a statistically significant variation in students' motivation between those instructed through Experiential Cooperative Concept Mapping and those taught using conventional methods. This indicates that concept mapping can significantly enhance students' motivation, reinforcing the notion that engagement and psychological aspects of learning are closely intertwined.

Moreover, Anih et al. (2019) used a quasi-experimental non-equivalent control group design to explore the impact of concept mapping on students' conceptual growth in physics. The experimental group learned optics-related concepts through concept mapping, whereas the control group was taught using traditional instruction methods. Data analysis indicated a notable difference in mean scores, with the concept mapping group performing better on the Test in Physics Concepts. Furthermore, the average test scores of male and female students showed no significant variation between the two instructional methods, emphasizing the broad applicability of concept mapping regardless of gender.

Additionally, Oni et al. (2023) found that incorporating peer feedback into self-constructed concept mapping significantly improved students' learning outcomes in chemistry. Their study revealed that students who engaged in concept mapping with peer feedback demonstrated a deeper understanding of intermolecular forces compared to those without feedback. This emphasizes the importance of fostering ownership and curiosity through group learning environments, further demonstrating that innovative instructional strategies like peer-supported concept mapping enhance active engagement and comprehension. In contrast, the absence of peer collaboration may hinder student understanding, highlighting the need for dynamic and interactive teaching methods.

More recently, Kpiranyam et al. (2024) demonstrated that the collaborative concept mapping method outperforms conventional methods in enhancing students' emotional intelligence and critical thinking in Biology. Their analysis highlights the benefits of group learning environments, which actively engage students and promote deeper comprehension of complex biological concepts. In contrast, reliance on conventional instructional methods may limit students' understanding and hinder the development of essential skills, emphasizing the need for innovative teaching strategies that facilitate active learning and critical engagement in the subject.

Based on the above studies related to psychological concepts, I observed that concept mapping has a notable impact on various psychological aspects of learning. It effectively reduced student anxiety and transformed negative attitudes toward challenging subjects like biology, chemistry and physics. Furthermore, the method enhanced student engagement and academic performance, addressing psychological barriers to learning. By improving perceptions of difficult topics and fostering motivation, curiosity, concept mapping emerged as a valuable tool in supporting both emotional and cognitive dimensions of education.

Based on the empirical studies related to cognitive levels, resercher found that concept mapping is a powerful tool for enhancing student learning and assessment. It effectively identifies knowledge gaps and evaluates cognitive processes when integrated with modified Bloom’s Taxonomy. Additionally, concept mapping significantly improves students' cognitive levels by organizing knowledge independently of cognitive style. Aligning concept mapping activities with Bloom’s Taxonomy fosters higher-order thinking and meaningful learning while countering rote learning tendencies. The quality of students' concept maps directly influences their performance, making concept mapping a valuable strategy in education.

Concept Mapping as a Tool for Assessing Cognitive Levels

Regarding cognitive level, the findings from Sanchez et al. (2010) suggested that using concept maps in conjunction with a modified Bloom’s Taxonomy provided a systematic way to analyze student learning and identify knowledge gaps. By having students construct concept maps before and after instruction, teachers were able to evaluate their cognitive processes and knowledge proficiency, facilitating more effective intervention and targeted teaching. This approach enabled educators to refine their pedagogical methods and monitor student progress over time, ultimately fostering deeper understanding and critical thinking skills.

Building on this, Jablokow et al. (2015) observed that concept mapping significantly improved students' cognitive level. Their major finding indicated that cognitive style and concept mapping performance were uncorrelated. This suggested that concept map metrics reflected students' knowledge organization rather than their cognitive style. As a result, cognitive style and concept mapping assessed different aspects of cognition and were complementary rather than overlapping.

Furthermore, Gorman (2018) explored the context of cognitive level within Bloom’s Taxonomy, finding that while concept mapping engaged students in higher-order thinking and promoted meaningful learning, common "fill in the blank" tasks often encouraged rote learning instead of critical thinking. The author suggested aligning concept mapping activities with Bloom's Taxonomy to enhance student engagement and foster meaningful learning. In similar vein, Pinandito et al. (2023) also added that concept mapping is an effective strategy for promoting higher-order thinking. The research indicated that the quality of students' concept maps significantly influenced their performance on higher-order thinking questions.

Concept Map and Gender

In respect to gender, Cheema and Mirza (2013) found that concept mapping significantly improved general science performance for both male and female students, though males achieved higher scores compared to females. Building on this, Sakata (2016) employed a quasi-experimental design to investigate the effect of concept mapping on students' physics achievement, revealing that the experimental group outperformed the control group, with male students achieving somewhat better results than female students. This supports the notion that concept mapping enhances physics learning outcomes.

In contrast, Appoji and Shailaja (2017) explored this dynamic in the context of physics, finding that concept mapping significantly improved girls' post-test academic achievement scores compared to their pre-test scores, whereas boys showed less improvement. Similarly, Sakiyo and Waziri (2015) demonstrated through a quasi-experimental design using ANCOVA that concept mapping significantly enhanced students' academic achievement in biology. They observed no notable difference in academic performance between male and female students within the experimental group. In line with these findings, Ogonnaya et al. (2016) reported that concept mapping led to higher achievement in basic science for both male and female students, with no significant gender differences in its effectiveness.

Additionally, Enebechi and Nzewi (2017) found that concept mapping significantly improved students' achievement in biology, with no significant gender interaction effect. Furthermore, Doris (2018) indicated that students who learned physics through concept mapping performed significantly better than those taught using conventional methods, with no notable differences between male and female students. Moreover, Ugwumba (2020) found that concept mapping significantly enhanced students' understanding of waves in physics, with no significant gender differences in performance, indicating consistent effectiveness for both male and female students.

This trend was further supported by Jena (2021), who observed that concept mapping significantly improved students' learning in Physical Science, without significant gender differences in achievement. Collectively, recent studies on the effect of concept mapping in science education revealed diverse outcomes regarding gender differences. Initial findings showed that concept mapping improved achievement in science and physics, with male students achieving slightly higher scores. However, subsequent research found that girls experienced more pronounced improvement in physics, challenging earlier results. Ultimately, further investigations reported significant enhancements in academic achievement for both genders, with the effectiveness of concept mapping remaining consistent regardless of gender.

Additional studies reinforced the method's effectiveness in boosting learning outcomes without significant gender differences.

Conceptual framework

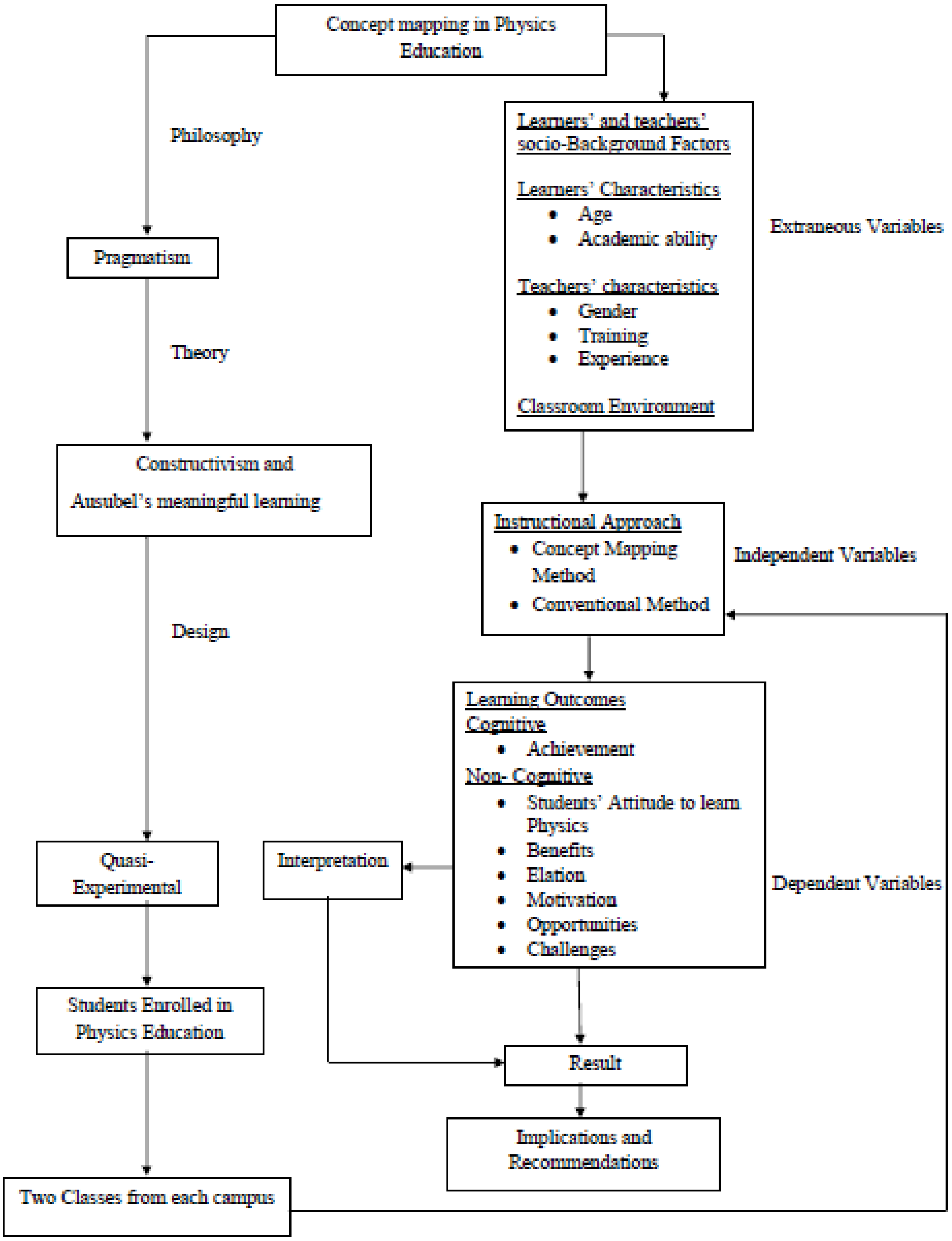
The conceptual framework provides direction for the research titled “Concept Mapping Method on Students' Achievement in Science Education at Higher Level,” highlighting key concepts and theories. Concept mapping is employed as a visual tool to enhance physics education, grounded in pragmatism, which emphasizes practical applications and real-world relevance in teaching. This method is aligned with constructivism and Ausubel’s Meaningful Learning Theory, which highlight the importance of connecting new information with existing knowledge, as well as with cognitivism theory, which concentrates on the cognitive processes like memory and problem-solving. The study utilizes a quasi-experimental design to contrast the concept mapping method with the conventional approach among students enrolled in physics. The independent variables are these two instructional methods, while the dependent variables include cognitive outcomes such as achievement and non-cognitive factors such as students’ motivation, attitude, regularity, and interest. Extraneous variables, including learners’ age, academic ability, and teachers’ gender, training, and experience, are carefully controlled to minimize their potential impact on the results.

Concepts like student engagement, teacher experience, and cognitive development are cross-cutting across the objectives. These concepts influence achievement, learning strategies, and perceptions, with cognitive achievement being influenced by learning strategies. Vertical relationships show how concept mapping impacts cognitive achievement and student engagement, while horizontal relationships highlight how teacher and student perceptions intersect, influencing both teaching and learning.

The data collection focuses on pre-test and post-test achievement scores for the first objective, cognitive performance assessments for the second, and interviews, reflective diaries, and observations for the third, fourth, and fifth objectives. These criteria guide data gathering to ensure a detailed understanding of how concept mapping impacts both cognitive and non-cognitive outcomes in physics education. Pre-test and post-test results evaluate changes in learning outcomes, with findings analyzed to inform implications and recommendations for enhancing teaching practices and educational strategies. Thus, the following is the conceptual frameworks on this study.

Figure 4

Conceptual framework in an educational environment



Note. Conceptual framework for using concept maps in an educational environment.

Summary

Inadequate methods of instruction execution have led to numerous cases of students underperforming in the subject of science (King'Aru, 2014). It is important to investigate ways that can improve both student achievement and enthusiasm in science, as physics is an essential foundation for physical science and other related disciplines in science. The researcher has extensively researched the relevant literature relative to the study's key themes. The existing literature was classified and assessed according to five major categories: philosophical perspectives, theoretical literature review, conceptual literature review, empirical literature review, and conceptual framework.

The philosophical underpinnings of this research were rooted in pragmatism, with theories of constructivism and Ausubel's Meaningful Learning Theory. The researcher sought to advance the understanding of how concept mapping enhances physics education by integrating these perspectives within a quasi-experimental framework.

The adoption of concept mapping in this study is anchored on constructivism, especially drawing on Ausubel's theory of meaningful learning and constructivist learning theory under the umbrella of pragmatism philosophy. These theories served as the theoretical underpinning for this study, which was explored through an in-depth review of the pertinent literature. In constructivist theories, students are regarded as active participants who construct knowledge through their own experiences. These theories emphasize the importance of arranging learning experiences and materials in a structured environment to promote the creation of order, meaning, and knowledge (Ausubel, 1968; Shuell, 1986).

The study of literature included a conceptual analysis as well as an empirical review of research findings concerning concept mapping and its influence on academic achievement and interest in science. According to the findings, concept mapping is an innovative educational tool that not only increases student engagement but also adds to greater levels of achievement when compared to conventional methods. Although extensive research has been conducted on concept mapping's impact across various science fields, there is a need for more focused research in physics. Further investigation into how concept mapping specifically affects student achievement and interest in physics is essential to address any field-specific nuances and refine instructional strategies.

Efforts were made under the conceptual framework to emphasize various concepts related to the research, such as the concepts of teaching and learning, certain methods of teaching, concept mapping, attitude, benefits, elation, motivation, and achievement.

The Implication of the Review for the Research

The implications from the extensive literature review are highly significant for the research, as they highlight the shortcomings of previous instructional methods in science education. The identified gaps and challenges in fostering students' achievement and enthusiasm in science, especially in physics, underscored the critical need for innovative approaches. Constructivism, pragmatism, and cognitivism were among the philosophical stances that were thoroughly examined and provided the theoretical foundation for the study's quasi-experimental design.

The implementation of concept mapping as a teaching technique was grounded in the conceptual foundations provided by constructivist learning theory and Ausubel's philosophy of meaningful learning. Aligned with constructivist principles, the study positioned students as active participants in the knowledge construction process, emphasizing the structured arrangement of learning experiences for meaningful knowledge creation.

The literature review's dual focus on conceptual analysis and empirical findings highlighted the innovative nature of concept mapping as an educational tool. While previous studies indicated positive outcomes in terms of increased student engagement and academic achievement, the specific context of physics education remained an underexplored domain. The identified research gap underscored the necessity for further exploration into the effects of concept mapping on students' performance and interest in the field of physics.

As a guiding structure for the research, the conceptual framework was carefully crafted to encompass important ideas including achievement, concept mapping, teaching and learning approaches, and non-cognitive aspects. The insights from the literature review provide a solid foundation for developing research questions, hypotheses, and the overall methodological approach. Ultimately, the literature review's conclusions shaped the study's theoretical framework and underscored how urgent it is to close the gaps found in order to improve scientific education overall, especially physics-related science education.

Research Gaps

Concept mapping is rarely utilized in physics education in Nepal, creating a significant research gap. Existing studies on educational practices in Nepal have primarily focused on conventional teaching methods, with limited exploration of innovative instructional strategies such as concept mapping. While some international research emphasizes the benefits of concept mapping in enhancing student engagement and comprehension, the applicability and effectiveness of this method within the Nepalese educational context remain inadequately investigated.

The effective use of concept mapping requires adequate materials and resources, which poses a challenge for resource-constrained schools in Nepal. The feasibility of integrating concept mapping within such settings, where teacher-centered approaches dominate, remains uncertain. The persistent mismatch between students' learning preferences and traditional instructional strategies highlights the need for research to explore how concept mapping can foster a more active learning environment tailored to students' needs.

The existing pedagogical challenges in physics education are compounded by the inadequate execution of instructional methods, contributing to students' persistent underperformance. Addressing the factors that hinder student achievement and enthusiasm in science education is crucial, particularly as physics serves as a foundational discipline for many scientific fields. Although previous research has acknowledged the potential of active learning strategies, there remains a scarcity of targeted studies focusing on the impact of these strategies on physics education in Nepal.

Philosophical perspectives, particularly pragmatism, offer a structured approach to analyzing how concept mapping influences education by emphasizing practical application and real-world relevance. The concept mapping method, deeply rooted in Ausubel’s Theory of Meaningful Learning, and Constructivism positions students as active participants in their knowledge construction process. While existing studies indicate that concept mapping can enhance engagement and achievement compared to conventional methods, the specific effects of concept mapping on physics education remain largely unexplored.

There is a pressing need for further investigation into how concept mapping influences student achievement and interest in physics. This study seeks to address this research gap by offering insights that will inform educators and policymakers in developing more effective instructional strategies tailored to enhance physics education in Nepal. By exploring the integration of concept mapping within established theoretical frameworks, this research seeks to promote meaningful learning experiences and active participation among students Bachelor level in science education.

Chapter III

Research Methodology

Introduction

This chapter focuses on the research methodology employed in the current study titled “Concept Mapping Method on Students' Achievement in Science Education at Higher Level”. The study is primarily experimental. Aiming to investigate the impact of concept mapping on students’ academic achievement in science education. The assessment of effectiveness encompassed two main dimensions: cognitive and non-cognitive results. Evaluating cognitive outcomes involved the use of achievement tests, while non-cognitive outcomes entailed measuring students' attitudes towards science education and their learning habits. Hence, the study incorporated both quantitative and qualitative methodologies to comprehensively explore these aspects.

To achieve the study's goal, this chapter explains the nature of the research, research philosophy, research design with the logical framework and data sources, data collection procedures, data collection tool, techniques of data reduction and analysis, method of minimizing errors, data validity and reliability.

Philosophical Perspectives of the Study

The research titled “Concept Mapping Method on Students' Achievement in Science Education at Higher Level” is deeply rooted in the philosophy of pragmatism and the learning theory of constructivism. Pragmatism underscores the importance of practical applications and real-world relevance in learning, asserting that knowledge is developed through active engagement and social interactions. This perspective seamlessly aligns with utilizing concept mapping as a practical tool to enhance students' understanding of physics by aiding visual representations of complex concepts and allowing students to connect new knowledge with their pre-existing cognitive frameworks.

Pragmatism served as a relevant philosophical perspective for investigating the effectiveness of the concept mapping method in science education. With its emphasis on practicality, action, and the utility of ideas, pragmatism aligned well with the applied nature of concept mapping as an instructional tool (Biesta, 2010). As outlined by James (2001), a key proponent of pragmatism, this philosophy encourages consideration of practical consequences and tangible outcomes. In the context of concept mapping, the study sought to assess the practical impact of the method in enhancing students' achievement. Pragmatism provided a practical and action-oriented approach, allowing the study to focus on both the theoretical underpinnings and the tangible benefits of utilizing concept mapping as an instructional strategy, promoting a holistic understanding of its impact on students' learning (Creswell & Creswell, 2017; James, 2001).

Pragmatism, as the philosophical backbone of this study, holds that knowledge is actively constructed through interaction with the world rather than passively received. Learning is not an isolated cognitive activity but an experiential and social process. This perspective aligns well with the objectives of concept mapping, where students interact with and manipulate knowledge in a way that makes sense to them. Concept mapping enables students to organize, visualize, and establish connections between scientific concepts, turning abstract ideas into coherent structures that foster deeper understanding. This resonates with the constructivist model of learning, which asserts that learners actively construct their own knowledge by connecting new information to prior experiences and understanding (Conceicao & Taylor, 2007).

The socio-cultural perspective within pragmatism is particularly relevant in this study. As Clancey (1989) argues, knowledge is generated through activities involving interaction among individuals, making learning a fundamentally social phenomenon. This study adopts this viewpoint by recognizing that concept mapping not only enhances individual understanding but also promotes group-based learning, where students engage in discussions, share insights, and build collective knowledge. The concept mapping method provides a platform for students to work together in connecting ideas and creating shared meaning, reinforcing the pragmatic idea that knowledge is co-constructed through social experiences.

Moreover, pragmatism emphasizes the role of experience in shaping knowledge. It suggests that learners construct their understanding by engaging in real-world activities that connect theory with practice. In this study, concept mapping serves as a link between theoretical knowledge and practical application. Students are not merely memorizing scientific concepts; they are actively organizing them in a way that demonstrates their understanding of how ideas relate to one another, mirroring the real-world process of scientific inquiry and problem-solving. This aligns with Ausubel’s Meaningful Learning Theory, which posits that learning occurs when new information is meaningfully integrated into a learner’s existing cognitive structure, rather than being superficially memorized (Ausubel, 1968). Concept mapping facilitates this meaningful integration by helping students anchor new scientific concepts to their prior knowledge, leading to deeper and more lasting learning outcomes.

Furthermore, pragmatism underscores the importance of the practical application of knowledge, emphasizing that education should not only impart theoretical insights but also equip students with the skills necessary for real-world problem-solving. Wrenn and Wrenn (2009) highlight that the pragmatic approach stresses the continuous interaction between learning and doing. In science education, concept mapping offers students a structured approach to comprehending scientific theories while simultaneously applying their understanding in analytical contexts. By visualizing relationships between concepts, students can engage in problem-solving scenarios, which is crucial in science education, where understanding the interconnectedness of ideas is essential.

Lastly, this study was closely aligned with constructivism, a theoretical framework that emphasized students' active role in the learning process and the construction of knowledge through meaningful experiences (Chen & Bennett, 2012). Constructivism posited that learning occurred when students connected new information with their personal past experiences, modifying them to form new understanding. Students were viewed as active learners who participated in creating their own knowledge when using concept mapping. The concept mapping method supported by the constructivist theory, which views learning as an active process of developing one's own mental models, by encouraging students to generate visual representations of their knowledge. This paradigm was apt for investigating how students constructed knowledge through concept mapping and how it influenced their achievement in science education. Teachers, in a facilitative role, guided students in creating concept maps, reflecting the constructivist view that educators should encourage active student participation (Gordon, 2009). Concept mapping not only helped students organize information but also fostered metacognitive skills, aligning with the constructivist goal of developing reflective and self-directed learners. In the constructivist classroom, students learned how to learn through experiences that encouraged continuous self-assessment and the development of expertise (Chen & Bennett, 2012; Gordon, 2009).

Constructivism further supports this approach by emphasizing that learners actively construct knowledge through their interactions with new material and by integrating it with their prior knowledge. This theory posits that meaningful learning occurs when students engage in processes that enable them to build and reorganize their mental frameworks. The concept mapping method, therefore, not only aligns with the pragmatic emphasis on practical learning experiences but also fosters constructivist principles by enabling students to visualize and connect concepts, resulting in a deeper understanding and improved achievement in science education.

Ontological, Epistemological, Axiological and Methodological Alignments

The researcher's choice of methods, techniques, and procedures was influenced by their underlying philosophical perspective. This perspective played a crucial role in how the research findings were interpreted, disseminated, and applied. The epistemological stance regarding unique knowledge and skills in the social sciences significantly shaped the study's conclusions. In this particular research, specific philosophical standpoints guided the overall approach and perspective adopted.

Ontology (nature of reality)

Ontology, as a philosophical discipline, examines the assumptions adopted to consider something logical or real and explores the essence of social phenomena under examination (Scotland, 2012). The researcher's ontological perspective influences how reality is perceived and presented in the investigation. Its significance within the scientific paradigm lies in its contribution to comprehending the elements that form the known world (Scott & Usher, 2011). In this study, the ontological alignment is grounded in a constructivist perspective, assuming that reality is subjective and multiple, with students actively constructing their own understanding of scientific concepts. The concept mapping method involves creating interconnected nodes representing various concepts, recognizing the multiplicity of perspectives and the subjective nature of knowledge construction. This approach acknowledges diverse individual perspectives and experiences, viewing knowledge as a product of personal interpretation and interaction with the learning environment. Therefore, the ontological stance of my study implies that reality is multiple, actively constructed by individuals. In this research, concept mapping is utilized to create interconnected nodes that facilitate the development of scientific understanding among students. This method emphasizes the dynamic and personalized nature of knowledge construction, highlighting the importance of diverse perspectives. By fostering active engagement with the material, concept mapping supports students in developing a comprehensive and individualized understanding of physics, ultimately enhancing their academic achievement and interest in science.

Epistemology (relationship of knower to the known)

Epistemology, derived from the Greek word "episteme," refers to the study of knowledge—its nature, acquisition, and dissemination (Cooksey & McDonald, 2011). It examines how knowledge is acquired, understood, and communicated, focusing on the different types and methods of knowing (Kivunja & Kuyini, 2017). In the context of this study, epistemology aligns with the constructivist perspective, which asserts that knowledge is not an objective entity but is actively constructed by individuals. This process includes incorporating new information with existing cognitive frameworks, emphasizing the role of prior experiences and existing knowledge in learning. Constructivist principles highlight the importance of experiential learning and reflective thinking, illustrating how knowledge is dynamically acquired through active engagement. In this research, concept mapping integrated instruction serves as a primary source of knowledge, emphasizing the inseparability of the knower and the known. This approach highlights that knowledge is constructed through the active process of linking new and existing information, reinforcing the interconnected nature of learning and understanding.

Axiology (role of values in inquiry)

The term "axiology" relates to the ethical considerations essential in crafting a study proposal and encompasses the philosophical foundation for making morally sound decisions (Finnis, 2011). Axiology entails the processes of establishing, assessing, and comprehending concepts related to appropriate and inappropriate behavior within the research context. It involves taking into account the values attributed to various components of the research, including participants, data, and the intended audience for presenting research findings. Consequently, through the ethical consideration of these elements, the axiology of my study was centered on advancing conceptual learning among students in the field of science. The research valued the perspectives, experiences, and voices of students, placing them at the center of the learning process. The axiological alignment reflects a commitment to fostering a positive and enriching educational experience for students through the implementation of the concept mapping method. This approach focuses on fostering critical thinking, self-reflection, and practical knowledge application, emphasizing the significance of these outcomes in science education and highlighting the inherent connection between inquiry and values.

Methodology

The present study employed a quasi-experimental design to assess the impact of concept mapping on students' achievement. Effectiveness was measured in terms of basic skills: cognitive and non-cognitive outcomes. Non-cognitive outcomes were assessed based on students' attitudes toward science education and their learning habits, while cognitive results were assessed via achievement tests. While qualitative techniques, such student interviews or observations, allow for a deeper study of students' experiences and perceptions, quantitative indicators, such as achievement scores, can provide statistical insights into the overall impact. This alignment acknowledges the importance of using three different data sources to enhance the validity of the research findings and to fully represent the variety of ways that the concept mapping approach works well in science education. This quasi-experimental approach integrates both quantitative and qualitative methodologies to strengthen the validity of the study findings and comprehensively evaluate the effectiveness of concept mapping in science education.

Design of the Study

The design of this study was a pretest-posttest non-equivalent control group experimental design (Campbell & Stanley, 2015). Cohen et al. (2007a) stated that this design was one of the most commonly used quasi-experimental designs in educational research. A similar term used was a nonrandomized comparison group design, specifically termed as the Nonrandomized Pretest-posttest Comparison Group Design (Ary et al., 2010). This study employed this design to assess the effectiveness of the concept mapping method on students' achievement in science education. Although the study was primarily experimental, a mixed-methods approach was employed to gain a thorough understanding of the intervention's impact.

Rationale for Quasi-experimental with Mixed-Methods Approach

A quasi-experimental design was chosen for this study for several reasons: (a) administrative restrictions at the chosen campuses prevented the use of random selection; (b) the realistic nature of the study conditions made a true experimental design impractical due to the complexity of human behavior and the difficulty in defining variables related to the non-cognitive aspects (Hatch & Farhady, 1982); (c) the ability of quasi-experimental designs to mirror real-world environments without disrupting the educational context, thus eliminating the 'artificiality' present in true experiments and demonstrating strong ecological validity (Bryman, 2012; Pelham & Blanton, 2018); (d) the compelling nature of results in quasi-experimental research, as argued by Bryman (2012), especially in evaluation research studies; and (e) the use of intact classes in quasi-experimental designs, which helped mitigate the threat of the Hawthorne effect that could arise when subjects were randomly selected and assigned to conditions during lesson periods.

The concept of ‘pre-test and post-test nonequivalent group design’ implies that participants were not randomly selected or assigned to conditions (Gay et al., 2012; Haslam & McGarty, 2014). Additionally, the term ‘nonrandomized’ referred to the use of pre-existing intact groups that lacked guaranteed equivalency (Campbell & Stanley, 2015). This was a quasi-experimental study, as two intact groups of Bachelor level’s science classes at constituent Education Campuses of Tribhuvan University in Kathmandu and Bhaktapur districts were taken.

While quantitative data from pre-test and post-test scores indicated overall learning gains, they only revealed the extent of academic improvement, without addressing the cognitive processes involved. To gain deeper insights, qualitative methods such as student reflections, interviews, and reflective diaries, classroom observations were incorporated. These methods provided a more detailed understanding of how students constructed and reorganized their knowledge through concept mapping, revealing the mental processes behind meaningful learning as outlined in Ausubel's Meaningful Learning Theory.

Qualitative data also highlighted the influence of concept mapping on student motivation, confidence, and curiosity—experiences that were not captured through quantitative measures. These insights showed how concept mapping enhanced student engagement, understanding, and problem-solving abilities, offering a more nuanced perspective of its effectiveness in fostering deeper cognitive engagement.

The study also identified challenges, such as students' difficulties with organizing concepts or adapting to the visual structure of concept maps. These challenges, uncovered through direct observations and student feedback, led to the refinement of instructional strategies to maximize the method's effectiveness.

Teacher perspectives were critical in understanding the practical application of concept mapping in the classroom. Interviews with teachers provided valuable insights into classroom dynamics, instructional adjustments, and strategies to help students effectively use concept maps. This qualitative data complemented the quantitative findings, offering a detailed evaluation of the method. The mixed-methods approach, integrating both quantitative and qualitative data, allowed for triangulation, strengthening the study's validity. By combining numerical data with detailed personal insights, the study offered a detailed understanding of the concept mapping method's impact on student achievement and learning processes.

The pre-test-post-test nonequivalent group design was schematically represented in the following manner:

Table 1

Experimental and quasi-experimental designs for research

Experimental	T_1	X	T_3
Control	T_2		T_4

Note. Adapted from Experimental and quasi-experimental designs for research: Ravenio Books by Campbell and Stanley (2015).

Where,

T_1 and T_2 = Pre-test for both experimental and control group.

X = Intervention only for experimental group

T_3 and T_4 = Posttest for both experimental and control group

Population and Sample of the Study

The target population refers to the group of individuals or areas intended for examination in a statistical study (Creswell & Creswell, 2017). Students taking the major subject Science Education at the Bachelor level in Tribhuvan University constituted the target population of this study.

Location of Study

The study was conducted in two constituent campuses of Tribhuvan University Faculty of Education in Kathmandu and Bhaktapur districts.

Sample of the Study

Selection of campuses

Two constituent campuses of Tribhuvan University, Faculty of Education, namely Mahendra Ratna Campus and Sano Thimi Campus situated in Kathmandu and Bhaktapur districts, were taken as the Control group and Experimental group campuses, respectively.

The campuses were selected purposively based on the population density of students studying science education, allowing the researcher to collect more data.

Additionally, the campuses were chosen for their proximity, enabling daily communication between them. The control and experimental campuses were then randomly selected from both.

Student's sample

The student sample for this study comprised 70 students from the control group and 95 students from the experimental group. To gain deeper insights into non-cognitive factors, such as challenges and opportunities associated with concept mapping, 8 students from the experimental group and 4 students from the control group were selected for interviews by using purposive sampling. This combination of quantitative and qualitative data helped to thoroughly examine the impact of the concept mapping method on students' achievement and experiences in science education.

Teacher's sample

The researcher personally taught both the experimental and control campuses. For some non-cognitive factors, such as challenges and opportunities, students' experiences shared with other physics teachers were observed through interviews with selected teachers in the sample campuses. Therefore, the teachers' sample included 7 physics teachers teaching at the Bachelor level in science education, with 5 teachers from the experimental campus and 2 from the control campus by employing purposive sampling.

Variable in the Study

Variable, as defined by Hatch and Farhady (1982), referred to an attribute of a person or object that varied among individuals or objects. They proposed that the independent variable was the primary variable under investigation, chosen, manipulated, and measured by the researcher. In contrast, the dependent variable was the variable observed and measured to assess the impact of the independent variable. In accordance with this perspective, Lane et al. (2013) described variables as properties or characteristics of an event, object, or person that could assume various values or amounts. They noted that experimenters often manipulated variables during research, with the variable manipulated by the experimenter termed the independent variable, while the dependent variable was the one used to assess the effect of the independent variable. The relations between different variables were mentioned in Appendix VII.

In this experimental design, the independent, dependent, and extraneous variables were explained as follows:

Independent/ Treatment variable

In this study, the treatment variable was the concept mapping method of instruction that was used in the classroom.

Dependent variables

The dependent variable was the response or the criterion variable that was presumed to be caused by or influenced by the independent treatment conditions and any other independent variables (Creswell, 2008). Learning outcomes i.e., achievement in Physics education and non-cognitive variables (elation, motivation, satisfaction, creativity etc.) were the dependent variables in this study.

Non-experimental Variables

Length of class period, time of day, college environment, teachers’ characteristics, students’ characteristics, content taught, tests and evaluation schemes etc. were the non- experimental variables.

Procedure to Control Extraneous Variables

Various types of variables were identified as potentially influencing the research findings. According to Best and Kahn (2006), variables represent conditions or characteristics manipulated, controlled, or observed by researchers. Independent variables, which could initiate changes in research outcomes, were defined as the conditions modified during the study. These variables functioned as inputs or stimuli to elicit specific responses, modified as needed within experimental conditions. The researcher actively controlled or manipulated these variables to understand their association with observed phenomena. Dependent variables, reflecting the outcomes of independent variables, were observed for changes resulting from manipulation. Intervening variables helped in establishing relationships between independent and dependent variables, while extraneous variables remained uncontrolled yet held the potential to impact results significantly. Research findings could thus become less reliable if these extraneous variables were not effectively managed (Best & Kahn, 2006).

In this study, meaningful learning in physics education across four cognitive levels was the independent variable, while students' scores on the Physics Achievement Test (PAT) within those levels served as the dependent variables. The concept mapping method used in classroom instruction acted as the intervening variable, while student achievement scores in physics were measured through Knowledge, Understanding, Application and Higher Levels, serving as dependent variables.

To maintain the validity of the experimental design, the impact of extraneous variables was carefully managed. If variables other than the independent variables were not controlled, the findings and external validity would diminish, thereby limiting the generalizability of results. To enhance research validity, both internal and external validity were strengthened simultaneously. Since this study aimed to examine the effect of the concept mapping method on physics achievement at the bachelor level in science education, identifying extraneous variables was essential. Mitigating the influence of these variables beyond the experimental variable helped ensure an accurate assessment of achievement. Accordingly, the following measures were implemented to control these variables.

Controlling Teachers' Qualifications and Experience

Since student achievement could be influenced by teachers' qualifications and experience, the researcher conducted lessons himself in both control and experimental settings, in line with schedules coordinated with campus authorities, department head, and subject teachers.

Controlling Subject Matter Differences

To prevent subject matter differentiation from affecting validity, both groups followed similar content of bachelor-level physics curriculum, prescribed by the Faculty of Education, Tribhuvan University of Nepal. The researcher developed general guidelines of teaching episodes for both the experimental and control groups.

Controlling Evaluation Scheme Differences

To minimize assessment differentiation, the same evaluation system was applied to both groups. The Physics Achievement Test (PAT), designed with input from science education experts and the supervisor, evaluated students across the four cognitive levels. Throughout the study, the researcher was always alert to observe students' creativity and their meaningful learning. The researcher himself administered, marked, or checked the students' test papers, thereby reducing the variation in evaluation schemes.

Controlling Teaching Time Differences

Both groups received the same scheduled teaching time, with coordination from the department head and subject teachers, to adhere to the prescribed time allocated for the physics curriculum.

Controlling Campus Facility Differences

Sampled campuses chosen for the study offered similar facilities like classroom and laboratory exists and were matched based on socio-economic backgrounds and academic performance records from the Office of the Controller of Examinations (OCOE), Tribhuvan University of Nepal. Academic records from the OCOE, Kathmandu, Balkhu, were analyzed. Both sampled campuses were considered almost equivalent based on the Bachelor and Master’s Level programs running in constituent campuses and a similar pass percentage rate of students.

Minimizing the Effect of Student Intelligence

Based on the demographic survey of students, student attitudes, and their intelligence as assessed by their teachers, the level of students was equated in both sampled campuses. To achieve this, researcher first conducted a demographic survey and reviewed the responses to ensure a balanced representation in both groups. He also administered an attitude survey to measure students' interest in science education and compared the responses to confirm similar motivation levels. Additionally, teachers assessed students' intelligence using a rubric, and research ensured a balanced distribution of cognitive abilities across both groups. This qualitative approach allowed me to manually equate the groups, ensuring they were similar in terms of demographics, attitudes, and intelligence, thus maintaining the integrity of the research design.

Minimizing Home Environment Influence

To balance home environment differences, the researcher encouraged increased classroom engagement over homework or external activities for both groups.

Addressing Students' Background Knowledge

The researcher assessed students' existing knowledge and attitudes toward physics through a pre-test to establish baseline equivalency across the groups.

Controlling Demand Characteristics

Demand characteristics, or participants' anticipation of the research purpose, were managed by reducing the likelihood of hypothesis guessing. The researcher, familiar to the campus environment as a regular teacher, helped minimize participants' awareness of the research purpose, thereby controlling for potential bias (Allen, 2017). To enhance research validity, both internal and external validity were simultaneously strengthened by applying procedures to control various threats.

Validity threats in the Experiment

Internal validity as well as external validity threats like history, maturation, regression, interaction effect, etc., were controlled during the study (Campbell & Stanley, 2015).

Control to the Threats of Internal Validity

History

Specific events or conditions, other than the experimental treatment, may occur between the beginning of the treatment and the posttest measurement and may produce changes in the dependent variable (Ary et al., 2010). These occurrences are known as the history effect. In this context, "history" doesn't pertain to past occurrences but rather to external events taking place simultaneously with the application of the experimental treatment. These events could lead to the observed outcomes even in the absence of any treatment. The risk of a history threat increases as the time gap between the pre- and post-measurements for the subjects becomes longer.

To mitigate the history effect in this study, several strategies were employed. The study was conducted over 55 days to minimize the likelihood of significant external events affecting the results. Both the experimental and control groups were exposed to the same external conditions, as the classes took place simultaneously. Regular monitoring and documentation of notable external events were conducted to account for any potential influences. By maintaining a controlled and consistent environment, the study aimed to isolate the effect of the concept mapping method on students' achievement, ensuring that observed changes could be attributed to the experimental treatment rather than external factors.

Maturation

It pertains to processes where alterations in respondents' behaviors result from the mere passage of time (independent of any specific event) along with the influence of the experimental variable. Changes in respondents' actions may arise from biological or psychological factors, such as the natural progression of age, hunger, fatigue, and similar factors. These alterations pose a risk to internal validity as they might generate outcomes that could be wrongly ascribed to the experimental treatment (Ary et al., 2010). Maturation may present challenges, particularly in longitudinal studies that gauge the effects of an intervention over an extended duration (Onwuegbuzie, 2000).

To address maturation effects, participants were selected within the same age range (21-23 years) to minimize age-related changes. This approach reduced variability due to different developmental stages and helped isolate the impact of the concept mapping method on students' achievement, ensuring observed changes were attributed to the experimental treatment rather than natural maturation.

Statistical Regression

Statistical regression typically happens when participants are chosen based on their exceptionally low or high scores on a pre-intervention measure (Onwuegbuzie, 2000). It is the inclination of participants with the highest scores on a test (e.g., a pretest) to achieve lower scores on a second, similar test (e.g., a posttest), and of participants with the lowest scores on a pretest to attain higher scores on a posttest. The pattern is for scores to regress or move toward a mean (i.e., average) or expected score. Consequently, individuals with extremely high scores regress (i.e., move lower) toward the mean, and those with extremely low scores regress (i.e., move higher) toward the mean (Gay et al., 2012).

To mitigate this risk in the study, participants were chosen to avoid extreme pretest scores, ensuring a more accurate assessment of the concept mapping method’s impact without the confounding influence of statistical regression.

Mortality

Mortality, also referred to as attrition, occurs when participants selected for a research study either do not participate at all or drop out of the study during various phases due to multiple reasons (Onwuegbuzie, 2000). To assess the mortality of groups, a researcher can collect demographic information about the participant groups before the study commences and then determine if there are any changes in the composition of the groups at the end of the study (Gay et al., 2012). The experimental mortality (attrition) threat arises when there is a differential loss of participants from the comparison groups, potentially leading to differences in the outcome measure even in the absence of treatment (Ary et al., 2010). The outcomes are thus unknown for these individuals.

This type of internal threat was controlled by excluding those participants from the research.

Testing

Testing, sometimes referred to as ***pretest sensitization***, is the possibility that a pretest will result in improved performance on a posttest. To put it another way, individuals' scores on a posttest may improve just by completing a pretest, even if they did not receive any teaching or treatment beforehand.

According to (Gay et al., 2012), testing is more likely to be dangerous when there is little interval between tests. Subjects may perform better on the posttest in designs that include a pretest because they might have learned more about the subject matter from the pretest, become more comfortable with the format and testing environment, have devised a plan for acing the test, or feel less nervous about taking it again. Participants become familiar with the outcome measure and remember responses for subsequent testing (Ary et al., 2010).

To mitigate this type of internal threat, the researcher employed an equivalent test comprising different items with the same cognitive level on a later test than those used in an earlier test. This threat was also minimized by incorporating a substantial time interval between the pretest and posttest (Ary et al., 2010).

Instrumentation

The instrumentation threat refers to unreliability, or lack of consistency, in measuring instruments that may result in an invalid assessment of performance (Gay et al., 2012). Instrumentation may threaten validity in several different ways. The threat to internal validity posed by instrumentation arises from alterations in the instruments employed throughout the study. The observed outcome might be attributed to changes in the measurement of the dependent variable from the initial occasion to the subsequent one, rather than the treatment itself. Modifications can include variations in the type of measuring instrument, difficulty level, scorers, test administration methods, the utilization of different observers for pre- and post-measures, and other related factors (Ary et al., 2010).

This type of internal threats was controlled by using same instrument for pre-test and post-test measures.

Compensatory/resentful demoralization

The benefits of an experiment may be unequal or resented when only the experimental group receives the treatment (Creswell, 2008).

Such internal threats were mitigated by offering benefits to both groups, including administering the treatment to the control group once the experiment concluded.

Selection bias

When there are notable distinctions between the experimental and control groups even before the experiment starts, selection becomes a risk. The assignment of individuals to the experimental or control group may be impacted by a selection bias, a nonrandom factor, raising questions regarding the groups' equivalency. In cases where the groups are not equivalent before the study, it becomes challenging to attribute any later differences to the treatment rather than the pre-existing disparities (Ary et al., 2010).

Selection bias is prone to happen when the researcher is unable to randomly assign subjects and must resort to using intact groups, as in a quasi-experiment. An intact group refers to a preexisting group, like a class or an independently formed group unrelated to the intended experiment. Therefore, it is crucial for researchers to make efforts to evaluate the equivalence of groups by comparing them across numerous variables (Onwuegbuzie, 2000).

Furthermore, as stated by Creswell (2008), this type of threat was controlled by randomly selecting participants, ensuring that characteristics had an equal chance of being distributed among the experimental groups.

Diffusion of Treatment

Treatment diffusion, or the seepage effect, takes place when participants from the control and experimental groups interact, leading to the spread of treatment influences into the control group, affecting the outcomes of both groups (Onwuegbuzie, 2000).

This threat was mitigated by ensuring the maximum possible separation between the two groups throughout the experiment (Creswell, 2008).

Control to the threats of External Validity

External validity threats arise when experimenters draw incorrect inferences from the sample data to other persons, other settings, and past or future situations (Creswell, 2008). Followings are some external variables and control measures of them.

Interaction of selection and treatment

Due to the specific characteristics of the participants in the study, the researcher is limited in generalizing the findings to individuals lacking these specific characteristics.

The researcher confines assertions about the effectiveness of concept mapping to the specific groups studied, recognizing that the outcomes may not be broadly applicable. To address this limitation, additional experiments were conducted with groups possessing distinct characteristics to explore how concept mapping influences achievement in diverse contexts (Creswell, 2008).

Interaction between testing and treatment

In this case, a pretest might change how sensitive or responsive the experimental participants were to the experimental variable, which could make the findings from a pretested population not representative of the effects of the experimental variable for the larger, non-pretested population that the participants were drawn from. Consequently, the researcher may be able to generalize findings to pretested groups but not to non-pretested ones (Ary et al., 2010).

Multiple Treatment Interferences

It likely to occur whenever multiple treatments are applied to the same respondents, because the effects of prior treatments are not usually erasable (Campbell & Stanley, 2015).

Interaction between setting and treatment

Due to the specific attributes of the participants' environment in an experiment, the researcher is limited in generalizing the findings to individuals in different settings.

This type of external threat was controlled by conducting additional experiments in new settings to determine if the same results occurred as in the initial setting.

Interaction of history and treatment

A researcher is unable to extrapolate experiment results to previous or future circumstances since they are time-bound.

To manage such threats, the researcher replicated the study at subsequent instances to ascertain if similar outcomes were observed as in the initial instance (Creswell, 2008).

Reactive arrangements

This would preclude generalization about the effect of the experimental variable upon persons being exposed to it in non-experimental settings (Campbell & Stanley, 2015).

Experimenter influence

The impact of the experimenter, in which the researcher gives participants clues that affect their performance, whether on purpose or accidentally, is another issue that undermines external validity. The findings of the study may depend on an experimenter who possesses particular personality traits or other attributes. According to Ary et al. (2010), the sheer presence of observers during an experiment may alter the participants' typical responses, making it risky to extrapolate the results from one group to another or to the general population.

Instrument for Intervention

Concept maps were employed as an intervention instrument based on the second year curriculum of Bachelor level of Science Education for 43 teaching episodes.

Reliability and Validity of Instrument

Instrument reliability, as described by Miller (2012), pertains to the degree to which a questionnaire, achievement test, observation, or any measurement method yields consistent results upon repeated trials. In the words of Burton and Mazerolle (2011), it denotes the stability or consistency of a test or measurement.

Instrument validity, as outlined by Miller (2012), is characterized by the degree to which the instrument consistently measures what it claims to measure across various instances or different assessors. In accordance with Burton and Mazerolle (2011), it signifies the extent to which an instrument accurately gauges what it is formulated or meant to assess. In simpler terms, it involves determining whether a test genuinely measures its intended objectives (Fulcher & Davidson, 2007; Hughes, 2003).

In the development of research instruments, validity is regarded as a paramount and crucial concept. An instrument would be valid if it measures what is intended measure. Validity is if a test is measuring accurately what it is intended to measure.

The reliability of the teaching Episode was established by assigning other teacher to teach some of the above teaching episodes. The validity of the teaching episodes was established through experts' judgement.

Preparation of Teaching Episodes

Ausubel (1960b) proposed that using concept mapping as an advance organizer is a practical and effective approach for educators to enhance learning outcomes in science classes by improving knowledge organization, integration, and facilitating deeper understanding. In this study, the teaching episodes for the experimental groups were prepared by using concept mapping method and divided into two sections: pre-class and post-class. Pre-class activities included reading books, establishing learning outcomes, exploring prerequisites (prior knowledge exploration), teaching, presenting advance organizers, and introducing learning tasks or materials. Similarly, post-class activities involved reinforcing cognitive organization through recapitulation, assigning tasks, and concluding the session. Some of the episodes were provided in Appendix XIV.

Lesson outcomes were aligned with the specified curriculum for the second year of physics education in a Bachelor of Science Education. Prerequisites relevant to each lesson were identified to explore learners' prior knowledge and experiences. Physics content was conveyed visually using the concept mapping method, initially differentiating concepts and then integrating sub-concepts, providing illustrations, and connecting them to the main concept for comprehensive understanding. Various activities based on prior knowledge exploration were employed. The researcher facilitated concept recapitulation through questioning and feedback. Additionally, students were given questions for further exploration and lesson revision as homework assignments.

Steps in Teaching Through Concept mapping as an Advance organizer

Researcher adopted the Advance Organizer Model, as outlined by Joyce et al. (2008), for constructing teaching episodes. For an episode on electrostatic induction, the model was applied in the following three phases:

Phase I (involves presentation of the advance organizer)

At this stage researcher conducted following steps:

- Clarified the objectives of the lesson

  Example: Students will understand the concept of electrostatic induction, define the terms involved in the process of electrostatic induction, and be able to demonstrate how it is applied to real-world scenarios.

- Presentation of the advance organizer in advance

Example: Introduce a diagram showing a charged object inducing a charge on a neutral object. Describe the key terms such as “induced charge,” “charged conductor,” and “electrostatic force.”

- Prompting awareness of relevant knowledge which is to be learnt.

  Example: Briefly review previous knowledge about electric charges and forces. Ask questions like, “What happens when two like charges come close to each other?” and “How does a neutral object interact with a charged object?”

Phase II (involves establishing connections to/from the organizer)

In this stage researcher performed the following steps:

- Presentation of the learning task or material by progressive differentiating content, process, product and learning environment.

  Example: Provide a series of progressively complex scenarios where electrostatic induction occurs. Start with a simple example like - what causes a plastic comb rubbed with fur to attract small pieces of paper? And why do we feel an electric shock when taking off woolen clothes? and then move on to more complex scenarios like induction in different materials or with varying distances.

- Explicitly organized and established a hierarchical logical order for learning materials.

  Example:

  Step 1: Explain the basic concept of electrostatic induction.

  Step 2: Demonstrate simple experiments with charged objects and neutral conductors.

Step 3: Explore real-world applications and problems involving electrostatic induction, such as the functioning of electrostatic precipitators or the role of induction in lightning.

Phase III (strengthening or recapitulation of the cognitive organization)

In the concluding phase, the researcher executed the following steps to recapitulate and provide feedback:

- The integrative reconciliation and active reception learning

  Example: Have students summarize the process of electrostatic induction, including key concepts and steps. Ask them to identify and discuss differences between electrostatic induction and other electrostatic phenomena like conduction.

- Prompting a critical approach

  Example: Engage students in a discussion about common misconceptions related to electrostatic induction, such as the idea that induction can occur without physical contact. Encourage them to consider and debate how electrostatic induction differs in various contexts or materials.

Attitude Test towards Physics Education

The inventory was employed to assess students' attitudes toward Physics Education in different theme, using a preliminary test conducted among two groups of students before the study commenced. The Attitude Test towards Physics Education included a checklist that utilized a 5-point Likert scale, where respondents indicated their level of agreement with statements on the following scale: Strongly Agree (SA)-5, Agree (A)-4, Neutral (N)-3, Disagree (D)-2, and Strongly Disagree (SD)-1. The reliability of this inventory was assessed using Cronbach's alpha test with SPSS version 20. The test yielded a coefficient of 0.867 for the control group and 0.644 for the experimental group, indicating different levels of internal consistency. The validity of the inventory was evaluated and confirmed through expert judgment. For further details, please refer to Appendix VI.

Tools for data Collection

Achievement test, observation, diary keeping (reflection), interview was used as tools during research.

Classroom Observation Form

The checklist was created for both the researcher and the students to evaluate the adequacy of classroom teaching and learning. The intention was to assess whether the teaching methods and learning outcomes met the required standards. The researcher utilized this checklist multiple times throughout the experiment to ensure consistent monitoring and evaluation of the teaching-learning process. For detailed information on the checklist, please refer to Appendix XVII.

Observation checklist for students' reflective behavior

To supplement the scores from the pretest and posttest, the researcher conducted observation checklists and interviews during teaching sessions for both the experimental and control groups. This was done to collect further insights into students' behavior, motivation, enthusiasm, elation, and other non-cognitive variables related to physics education. The inclusion of the observation component in the research aimed to gather direct insights into social processes within an authentic context, following the framework proposed by Silverman (1993). Furthermore, Merriam (1998) emphasized that one of the reasons for researchers to collect data through observation is to comprehend the context better. Observations were also suggested to provide knowledge of the context or to highlight specific incidents and behaviors that could serve as reference points for subsequent interview.

In the course of the observation, field notes served as the chosen instrument for the researcher. This decision was prompted by the fact that the participants were not conscious of their actions being documented. Opting for this tool enabled the researcher to fulfill the study's second objective, which involved gaining insights into students' conduct, motivation, enthusiasm, satisfaction, and other non-cognitive factors associated with Physics education.

Field notes, as outlined by Fraenkel et al. (2012) were the detailed notes observers took in the educational setting. These notes documented what was happening, what they heard, saw, experienced, and thought during the process of collecting and reflecting on their data. For comprehensive details on the checklist, please refer Appendix XVIII.

Observation checklists for classroom

The researcher utilized a student observation checklist to assess students individually or in groups, focusing on their academic and instructional behaviors, as well as their interactions in the classroom. The observation checks facilitated an examination of the researcher’s teaching practices, enabling adjustments to better address the learning needs of the students and identify strategies to address any disruptive behaviors. In this regard, the researcher observed the class to address the following:

- How was the method of concept mapping instruction followed among students?
- Did he/she adhere to the instructions and complete the tasks?
- Did the student work diligently and neatly?
- Was he/she attentive to instructions and tasks?
- Did the student display any disruptive behaviors in class?

- How was his/her attention span during the observation?
- What was his/her activity level during the observation?
- Did he/she interact appropriately with peers in an academic setting?

In accordance with the study's requirements, the researcher participated in teaching process as a facilitator (insider) and simultaneously assumed the role of an observer (outsider) to contemplate classroom behavior.

Best and Kahn (2016) pointed out that when researchers were sole observers, there was an unconscious tendency to see what they expected to see and overlook incidents that didn't fit their theories. Their values, feelings, and attitudes, influenced by past experiences, might have distorted their observations. Engaging several others who were well-prepared as observers was recommended to address these potential biases.

This was the reason why supervisors were asked to engage in the study. Consequently, to establish the reliability of observations, supervisors were requested to occasionally participate in the study and observe the researcher's class.

Interviews

Best and Kahn (2016) asserted that the interview was, in a sense, an oral questionnaire wherein the subject or interviewee provided the necessary information orally and face-to-face (or via the telephone), as opposed to writing down the responses.

Considering ethical considerations, the researcher conducted each interview with audio-tape recording. Interviews were preferred to be taped because they were more convenient, less expensive, and eliminated the need for writing during the interview, which could be distracting for the subject as well as the interviewer. The tapes were replayed as many times as required for a thorough and impartial study at a later date, and full transcripts of the recorded interviews were created. In addition to capturing the words, the tapes preserved the tone of voice and emotional impact of the responses (Best & Kahn, 2016).

Interview schedules

Interview schedules for teachers and students were prepared to gather qualitative data on the effect of the concept mapping method for the experimental group and the impact of the conventional method of teaching for control group (please refer to Appendix XV). The validity of these interviews was established through expert judgments, ensuring the relevance and accuracy of the questions. Conducted multiple times, each interview served a distinct purpose, allowing for a comprehensive comparison of responses. This approach was crucial for understanding how both teaching methods facilitated the transition from students' initial cognitive levels to more advanced, logical thinking through hands-on experience. These interviews, conducted both formally and informally, provided valuable insights into the cognitive development process and the educational benefits of using concept mapping, as well as the conventional method, in science education.

To evaluate the impact of the concept mapping method, researcher interviewed two teachers from the control group and four from the experimental group, along with four students from the control group and eight from the experimental group. The interviews focused on pretest and posttest performance, with pretest interviews gauging familiarity with prerequisite knowledge and establishing baseline levels. Additionally, researcher gathered insights from experimental group teachers and students regarding their experiences with the concept mapping method, while also interviewing control group teachers and students to obtain diverse perspectives on the conventional teaching methods typically employed in classrooms.

Students were categorized as High, Average, and Low achievers based on their academic achievements in physics. This stratification allowed me to gather diverse perspectives and assess how different levels of prior knowledge and performance influenced their experiences with both teaching methods, helping to identify specific challenges and opportunities across varying levels of academic proficiency.

Researcher observation

The researcher kept a regular diary to track his insights regarding the effect of the new teaching method. The aim was to assess whether students derived meaning from what they observed, heard, perceived, and worked on within their groups.

Murnane and Raizen (1988) provided the following indicators of learning in science:

- made quick responses in performing acts that were relevant to an area of Physics.
- developed pattern-recognition skills in relevant knowledge.
- organized knowledge (information) in memory for individuals or for groups of students.
- retrieved skills of information in related area of Physics.
- how students conceived of a problem had much to do with their success in solving it.
- developed procedural knowledge or metacognitive knowledge.

Moreover, depending upon student activities, attitudes toward science, and Scientific habits of mind Murnane and Raizen (1988) also provided the following indicators of student behaviors in Science:

- explained something to the class verbally.
- took some action on a problematic task.

- Engaged in reflection, i.e., active, interested involvement in learning science.
- offered some argument for verification.
- appraised some work critically.
- worked with a more skilled peer or acted as a more skilled peer.
- perceived knowledge of science in connection with their daily life, career development, health management, community involvement, and responsibilities as citizens.

Any student who had engaged in any of the above activities showed that he or she made sense, transferred their knowledge to a higher level, and engaged in learning and correcting meaningfully.

Achievement test

Originally, Bloom and Krathwohl (1956) proposed various levels within the cognitive domain to promote the progression of knowledge. These levels, including knowledge, comprehension, application, analysis, synthesis, and evaluation, have since undergone revision.

As per Anderson et al. (2001), the updated version of cognitive domain levels is delineated as follows: remembering (recalling pertinent facts and knowledge stored in long-term memory), understanding (constructing meaning from acquired information), applying (utilizing acquired knowledge in novel and similar contexts), analysis (breaking down concepts into interconnected parts or components), evaluating (cultivating judgment skills based on established criteria for received information and facts), and creating (employing information and knowledge in an innovative manner). In contemporary secondary-level curricula, educational objectives are categorized into knowledge (for remembering, understanding, and application) and higher-order abilities. The higher ability level encompasses analysis, evaluation, and the creative aspects of the revised Bloom's taxonomy (Ministry of Education, 2015).

As outlined by Bloom and Krathwohl (1956), the cognitive domain levels in a child have been categorized, with the simplest being the recognition of facts, denoted as the knowledge level, and the most advanced residing in the abstract and mental realm, designated as the evaluation or judgmental level. Other cognitive domain levels, such as comprehension, involve the child's ability to understand concepts, interpreting materials by explaining given conditions and summarizing them based on their understanding. Similarly, application signifies the child's capacity to use and apply acquired knowledge in novel methods, rules, and concepts, relating to mathematical principles, laws, and theories. Through the integration of knowledge and understanding, learners can apply their acquired knowledge in new and similar situations, falling within the realm of the application level.

Moving on to the analysis level, students enhance their skill in organizing and categorizing objects based on their characteristics. Achieving this level of cognitive domain requires students to draw upon their prior knowledge and learning experiences. Another tier within the cognitive domain is the synthesis level, where students cultivate the ability to identify relationships between wholes and parts, categorizing their learning according to different themes. This level of learning encompasses all the previously mentioned cognitive domain levels.

For each of the subject contents, Electrostatics and Direct Current Circuits, the researcher developed two sets of Physics Achievement Test (PAT) items, each comprising 40 questions designed to be completed within 45 minutes. To address internal threats such as testing bias, two parallel forms of the test were created, ensuring they were equivalent in cognitive difficulty. Each form included test items across four levels of Bloom's Taxonomy: (a) Knowledge, (b) Comprehension, (c) Application, and (d) Higher Order Thinking (Analysis, Synthesis, and Evaluation). These cognitive domains were chosen to provide a comprehensive assessment of students' understanding, from basic recall to complex analytical and evaluative skills. For comprehensive details on the checklist, please see Appendix VIII.

Reliability and validity of Tools

The data for this study was gathered through the tools of an achievement test, observation, and interviews. To uphold the precision of the data, the instruments employed in this study necessitated two essential attributes of any measurement procedure: validity and reliability (Miller, 2012). As a result, a pilot test was conducted at a different campus not encompassed in the study sample to assess the validity and reliability of the tools. The pilot test included 40 multiple-choice questions from Physics education. Following the pilot test, item analysis was performed, calculating Difficulty index and Discrimination index as outlined below:

Difficulty Index

The difficulty index of an item is characterized as the proportion or percentage of examinees who answered a specific test item correctly. It stands as a crucial parameter in item analysis, ranging from 0 to 1 or 0% to 100% (Mahjabeen et al., 2017; Mukherjee & Lahiri, 2015). As outlined by Mahjabeen et al. (2017), the researcher have applied the following formula to compute the difficulty index.

$$\text{Difficulty index (DIF I)} = \frac{\text{PT+PB}}{\text{NT+NB}} \text{ or } = \frac{\text{PT+PB}}{\text{N}}$$

Where, PT = The number of right answers in the high score group

PB = The number of right answers in the low score group

NT = The number of students in higher group

NB = The number of students in lower group

N = Total number of students in both higher and lower groups

In this research, researcher conducted an item analysis to calculate the Difficulty Index (P-Value) for the Physics Achievement Test (PAT) items. This process involved categorizing the participants into two groups: the upper 27% (PT) and the lower 27% (PB) based on their total scores, with each group comprising 7 students out of 24. The Difficulty Index was used to determine the relative difficulty of each test item, with a value range indicating whether an item was easy, average, or hard. According to the criteria adapted from Obon and Rey (2019), researcher interpreted the difficulty index by following criteria:

Table 2

Interpretation of the difficulty index

Percentage Range	**Difficulty Index**	**Interpretation**	**Action**
75% - 100%	0.75 – 1.0	Easy	Revise or Discard
26% - 74%	0.26 – 0.74	Average	Retain
0 – 25%	0.25 or below	Hard	Revise or Discard

Note. Adapted from Analysis of Multiple-Choice Questions (MCQs): Item and Test Statistics by Obon and Rey (2019).

Discrimination Index (DI)

The discrimination index pertains to the capability of an item to distinguish between the superior (high achievers) and the inferior (low achievers) groups. It spans from -1 to +1. The item is considered to be effective and is discriminating if it has a higher value (Mukherjee & Lahiri, 2015; Musa et al., 2018). Item discrimination is defined as "the ability of an item to differentiate between students of higher and lower abilities" by Gajjar et al. (2014).

As per Gajjar et al. (2014), the researcher have utilized the subsequent equation to ascertain the discrimination index:

$$\text{Discrimination Index (DI)} = \frac{2(\text{PT} - \text{PB})}{\text{N}}$$

Where, PT = The number of right answers in the high score group

PB = The number of right answers in the low score group

N = Total number of students in both higher and lower groups

So, I have calculated the discrimination index by following criteria:

Table 3

Interpretation of the range of discrimination index

Range of Discrimination Index	**Interpretation**	**Action**
≥ 0.50	Very Good Item	Definitely Retain
0.40 – 0.49	Good Item	Very Usable
0.30 – 0.39	Fair Quality	Usable Item
0.20 – 0.29	Poor Item	Consider Revising
≤ 0.20	Very Poor	Possibly Revise or Discard

Note. Adapted from Analysis of Multiple-Choice Questions (MCQs): Item and Test Statistics by Obon and Rey (2019).

For detailed information on the item analysis of the pretest and posttest, please refer to Appendices II and IV, respectively.

Furthermore, the reliability coefficient of the achievement test was calculated using the Kuder-Richardson formula 21. Other tools, such as observations, checklists, and reflective diaries, were evaluated for reliability using the test-retest method. The validity of these tools was established through expert opinion, including input from the supervisor, subject teachers, and university professors.

Kuder-Richardson 21 test

This statistic estimates the consistency between items. A high value suggests a strong connection between items, while a lower value indicates a weaker relationship. The formula includes the mean or average score of the exam. This can help researcher to measure the reliability of the research instrument. KR-21 is usually used in non-continuous values. Items scored or coded 1 – 0. The values also range from 0 to 1 (Lyerly, 1958).

In this study, researcher calculated the reliability coefficient values using the Kuder-Richardson-21 (KR-21) test to assess the internal consistency of the test items. The KR-21 test was calculated using the formula:

$$r = \frac{n}{n-1}\left[1 - \frac{X(n-X)}{n\sigma^2}\right]$$

Where, n = Number of items

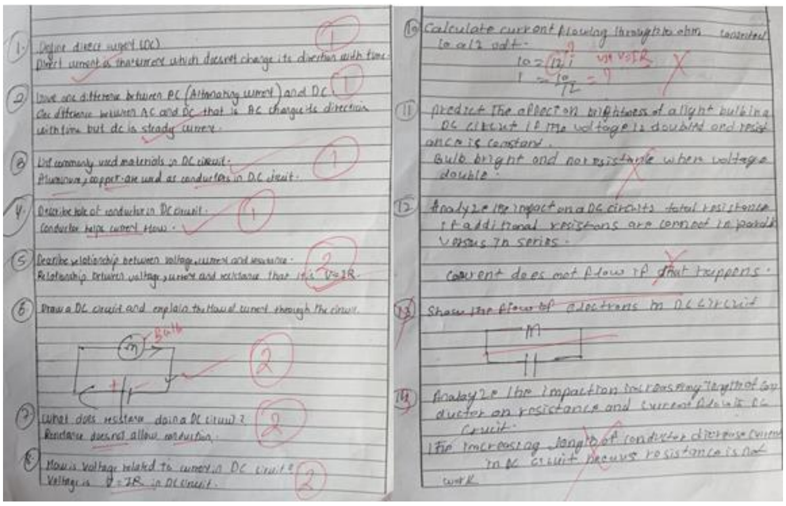
X = Mean

σ = Standard deviation

The reliability coefficient (r) obtained from the pre-test was 0.79, demonstrating a high level of internal consistency. Similarly, the post-test yielded a reliability coefficient of 0.78, confirming that the test items consistently measured the intended construct. For comprehensive details on the reliability testing of the test items in the pretest and posttest, please see Appendices III and V, respectively.

Scoring the data

In the achievement test administered after the post-test, subjective questions were also given to the students to further validate the research question. The scoring system for these subjective questions was carefully structured to reflect different cognitive levels, with each question assigned a specific weight based on its difficulty. Knowledge-level questions, which measured conceptual understanding and required simple recall of information, were assigned 1 point each. Understanding-level questions, which assessed procedural understanding and required both information and skill application, carried 2 points each. Application-level questions, which demanded the application of both knowledge and comprehension, were assigned a weight of 4 points. Finally, higher-order thinking questions, which required analysis, synthesis, and evaluation, were assigned 5 points each. This approach ensured that the assessment accurately captured the students' depth of understanding and their ability to apply their knowledge effectively.



1. Define direct current (DC).
Direct current is that current which doesn't change its direction with time.
1

2. Give one difference between AC (Alternating current) and DC.
One difference between AC and DC that is AC change its direction with time but dc is steady current.
1

3. List commonly used materials in DC circuit.
Aluminum, copper are used as conductors in D.C circuit.
1

4. Describe role of conductor in DC circuit.
Conductor helps current flow.
1

5. Describe relationship between voltage, current and resistance.
Relationship between voltage, current and resistance that it's V=IR.
2

6. Draw a DC circuit and explain the flow of current through the circuit.
Bulb
2

7. What does resistance do in a DC circuit?
Resistance doesn't allow conduction.
2

8. How is voltage related to current in DC circuit?
Voltage is V=IR in DC circuit.
2

10. Calculate current flowing through 10 ohm connected to a 12 volt.
10 = 12 i   V = IR
I = 10/12 = ?

11. Predict the effect on brightness of a light bulb in a DC circuit if the voltage is doubled and resistance is constant.
Bulb bright and not resistance when voltage double.

12. Analyze the impact on a DC circuits total resistance if additional resistors are connect in parallel versus in series.
Current does not flow if that happens.

13. Show the flow of electrons in DC circuit

14. Analyze the impact increasing length of conductor on resistance and current flow in DC circuit.
The increasing length of conductor decrease current in DC circuit because resistance is not work.

Procedure Followed to Conduct the study

In the execution of this study, the process was segmented into three stages as delineated below:

Phase I: Pre-Experimental Stage

Initially, the research problem was identified through a review of existing literature and an assessment of gaps in current knowledge. This process was followed by conducting library research to build a theoretical foundation and position the study within the broader academic context.

During this phase, the collection of consent papers from campuses was carried out, alongside the preparation of instructional materials, standardization of teaching episodes, achievement tests, pilot testing of test items, item analysis, and the preparation of an interview schedule. Additionally, the attitude of students toward Physics Education was measured before the experiment began.

Furthermore, during this stage, a pretest (achievement test) was administered to the students. The pretest, in the form of multiple-choice questions with 40 items in Physics, each with four distractors of different cognitive levels, was given to both the control and experimental groups after piloting it with another group (excluding the sampled group). This step was undertaken to evaluate the initial proficiency of students in Physics education and to confirm that there was no notable difference in the initial proficiency between the two groups.

Phase II: Experimental Stage

In this phase, the actual experiment was conducted with students split into control and experimental groups. The control group received instruction through conventional methods, while the experimental group employed the concept mapping method. This method involved several key activities: students were taught using concept maps to understand and connect key concepts in the topics of electrostatics and direct current circuits. In the lessons, concept maps were used to visually organize and present information, aiding students in understanding scenarios such as why a charged balloon sticks to a wall or why dust is attracted to a TV screen, which illustrated concepts like "induced charge" and "inducing charge." In direct current circuits, concept maps helped clarify ideas related to current flow, resistance, and circuit design. Group discussions allowed students to collaboratively explore these maps, deepening their understanding of complex real-world applications, such as the operation of electrostatic precipitators and the functioning of basic electrical circuits. Students also maintained reflective diaries to document their learning experiences and the insights gained from being taught with concept maps, comparing these experiences with those from conventional teaching methods. To collect qualitative data, observations, interviews with selected teachers and students, checklists, and reflective diaries were utilized, providing a comprehensive understanding of the concept mapping method's effectiveness and the students' experiences.

Phase III: Post-experimental Stage

The posttest, comprising multiple-choice questions with 40 items in physics (in a parallel to the pretest) with four distractors of the same cognitive levels as in the pretest, was administered to both the control and experimental groups to assess the effect of the interventions. Following the experiment, the collected quantitative and qualitative data were analyzed to draw conclusions. Moreover, the process of writing an analytical report was initiated to complete the dissertation.

Activities Among Students

To ensure the rigor of the study in understanding how students effectively learned using the concept mapping method, researcher incorporated both quantitative outcomes and qualitative data. After teaching the lesson, he engaged students in constructing concept maps both individually and in groups. They created their own concept maps, which helped them organize and express their understanding. To deepen their comprehension, researcher provided two pre-made concept maps: one missing connecting verbs and another missing key concept. Students filled in these gaps, reinforcing their understanding and creating a more interactive, joyful, and positive classroom environment. To gain deeper insights, he conducted interviews with

students from both the experimental and control groups. These interviews provided valuable perspectives on how the concept mapping approach influenced their ability to solve questions related to direct current and conduction mechanisms at various cognitive levels, thus supporting the quantitative findings with qualitative evidence. The teacher-generated and student-generated concept maps were included in Appendix XII.

Data Triangulation Procedures

Denzin (2010) identified four forms of triangulation: data triangulation, investigator triangulation, theory triangulation, and methodological triangulation. In this study, investigator triangulation was not applicable because the researcher was solely responsible for both data collection and analysis. Consequently, the researcher implemented data triangulation, theory triangulation, and methodological triangulation. Quantitative data were obtained through physics achievement tests, while qualitative data were collected through interviews with teachers and students, classified as high, average, and low achievers. The researcher utilized statistical tools to analyze the quantitative data, whereas qualitative data were processed using ATLAS.Ti 9, facilitating effective data triangulation. Additionally, the researcher compiled a self-reflection report based on active classroom involvement and observations of peer and teacher interactions, which further enriched the data collected.

Theoretical Triangulation of Data

Theoretical triangulation involved the application of multiple theories to investigate the same phenomenon from various perspectives. This study was grounded in a philosophical framework of pragmatism, which integrated Ausubel’s theory of meaningful learning (1968) and constructivist learning theory (1980). The triangulation of these theories provided a robust foundation that bolstered the findings of the study. Specifically, the research explored the influence of concept mapping on physics achievement among bachelor's-level students in science education, focusing on four cognitive domains. Furthermore, it addressed learning strategies and identified the opportunities and challenges encountered by both teachers and students in employing concept mapping within physics instruction. Through this approach, theoretical triangulation was effectively applied to enhance the depth and validity of the inquiries undertaken in the research.

Methodological Triangulation Procedures

For methodological triangulation, the study utilized both quantitative and qualitative data collection and analysis methods, adhering to an explanatory sequential mixed-methods design (Creswell & Creswell, 2017). The researcher first collected quantitative data through structured methods, which included the construction of tools, pilot testing for validation, reliability testing, and subsequent administration to the sample group. Following the quantitative phase, qualitative data were gathered from interviews with teachers and students, along with the researcher's self-reflection on the classroom experience. This qualitative data was analyzed using ATLAS.Ti 9 software. In the context of experimental research, controlling extraneous variables was crucial for enhancing both internal and external validity. As a result, various measures were implemented to address potential threats, thereby strengthening the study's overall internal validity.

Techniques for data analysis for quantitative and qualitative data

The data nature for this research encompassed both quantitative and qualitative aspects. Quantitative data were derived from the achievement test developed by the researcher, aligning with the curriculum of Bachelor level in

Science Education across four levels of the cognitive domain. These quantitative data underwent analysis using SPSS version 20, employing descriptive and statistical methods at a significance level of 0.05. The stated hypotheses were subjected to specific statistical tests for validation. As it employed quasi-experimental method of data analysis, the results obtained from the quantitative data were elaborated and supported by using qualitative data obtained from interviews and the researcher's self-reflection report. The qualitative information gathered was analyzed with the assistance of ATLAS.ti 9, focusing on themes related to the problems and obstacles faced by students and teachers. This analysis highlighted several opportunities offered by concept mapping in teaching and learning. For students, concept mapping promoted a more profound comprehension of intricate concepts by visually organizing information and clarifying relationships between ideas. For teachers, it provided a structured approach to presenting content and assessing student comprehension, while also fostering more interactive and engaging classroom environments. Interviews with teachers, and selected students of high, medium, and low performance levels were coded, categorized, and generated themes in ATLAS.ti 9. In this thesis, researcher included a word cloud (Figure below) generated with ATLAS.ti 9 to visually represent the frequency of key terms in the dataset. This tool highlighted dominant themes and provided an initial overview that guided the detailed thematic analysis. The non-cognitive elements, including attitude, benefits, elation, motivation, and perception were analyzed thematically in line with the approach described by Braun and Clarke (2006). This involved observations, maintaining a diary (self-reflection), and

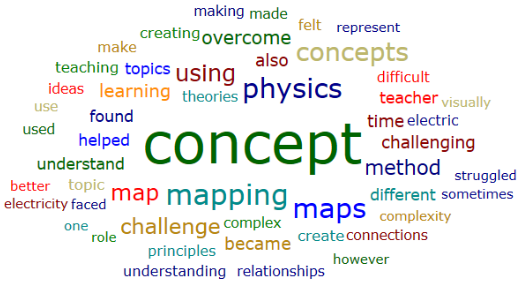


Figure: A word cloud

transcribing and analyzing interview tapes. This approach helped me clearly see how concepts were related and compare them with the repeated data. The analysis process with ATLAS.ti 9 involved 19 documents, 739 quotations, and 28 codes, which were categorized to generate various subthemes and themes based on the objectives and research questions.

The different phases of thematic analysis for this study are summarized in Table 4 below.

Table 4

Phases of thematic analysis

Phase	Description of the process
1. Acquainting with the data	Transcribing the data when needed, thoroughly reading and revisiting the information, and jotting down initial thoughts.
2. Creating preliminary codes	Assigning codes to the data and organizing data associated with each code.
3. Identifying potential themes	Grouping codes into possible themes and collecting all data related to each potential theme.
4. Reviewing themes	Creating thematic map of the analysis
5. Clarifying and labeling themes	Clarify the details of each theme, creating precise definitions and labels for each one.
6. Preparing the final report	Examine the analysis, connect it back to the research question and existing literature, and produce a comprehensive scholarly report of the findings.

Note. Adapted from Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101 by Braun and Clarke (2006).

In conclusion, researcher analyzed the data from interviews thematically, following the process outlined in the table, by reviewing and organizing the data, identifying and refining themes, and ultimately producing a detailed report that connected the findings to the research questions and literature.

Summary

In this chapter of the study explores the effectiveness of the concept mapping method on students' achievement in science education. The research, primarily experimental, investigates the impact of concept mapping on both cognitive and non-cognitive outcomes, grounded in pragmatism integrating Ausubel theory of meaningful learning and constructivism. The methodology employs an experimental design, specifically a pretest-posttest non-equivalent group design, with a focus on Science Education students at the Bachelor level in Tribhuvan University. The study meticulously addresses internal and external validity threats, employs a set of controls, and uses reliable and valid instruments, including achievement tests, observation checklists, interviews, and reflective diaries. Thematic analysis is used to qualitative data, ensuring a robust exploration of the research questions and objectives throughout the study.

Quantitative data analysis was conducted using SPSS version 20, employing descriptive, inferential and statistical methods at a significance level of 0.05. For qualitative data analysis, ATLAS.ti 9 is utilized to code, categorize, and thematize interviews and reflections, enhancing the depth and credibility of the research findings.

Chapter IV

Analysis and Interpretation of Data

Introduction

This chapter focuses on the analysis of quantitative data acquired based on the four levels of the cognitive domain. The data were acquired using a physics achievement test developed by the researcher, and its validity and reliability were validated using expert opinion and the Kuder-Richardson-21 test, as stated in the previous section. Internal consistency for each test item was also determined using item analysis. The acquired data was analyzed using both descriptive and statistical tests.

Section 1. Analysis and Interpretation of Quantitative Data

Analysis of Attitude Test Towards Physics

In the analysis phase, data from the preliminary attitude test toward physics education in both the control and experimental groups were examined to detect trends and variations. Statistical methods were employed to evaluate any notable differences in attitudes, offering insights into factors shaping students' views on physics before the intervention. This helped establish a clear understanding of initial attitudes prior to the main study.

Analysis of Attitude Test for Control Group

Table 5

Attitude Test for Control group (N =71) in terms of Enthusiasm toward

Factor I: Enthusiasm toward Physics	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
I appreciate learning about physical occurrences and their descriptions the most	0	0	6	45	20
	0.0%	0.0%	8.5%	63.4%	28.2%
	9	23	17	16	6

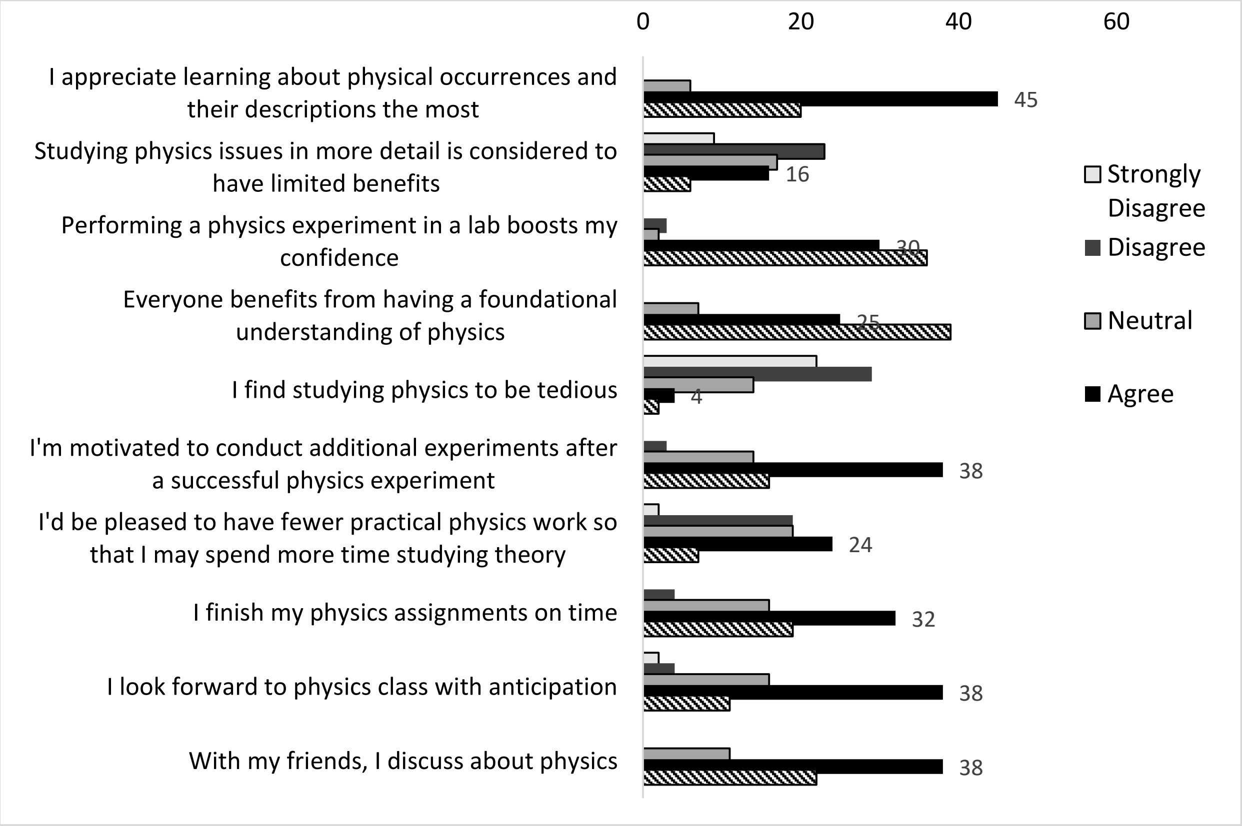
Studying physics issues in more detail is considered to have limited benefits	12.7%	32.4%	23.9%	22.5%	8.5%
Performing a physics experiment in a lab boosts my confidence	0	3	2	30	36
	0.0%	4.2%	2.8%	42.3%	50.7%
Everyone benefits from having a foundational understanding of physics	0	0	7	25	39
	0.0%	0.0%	9.9%	35.2%	54.9%
I find studying physics to be tedious	22	29	14	4	2
	31.0%	40.8%	19.7%	5.6%	2.8%
I'm motivated to conduct additional experiments after a successful physics experiment	0	3	14	38	16
	0.0%	4.2%	19.7%	53.5%	22.5%
I'd be pleased to have fewer practical physics work so that I may spend more time studying theory	2	19	19	24	7
	2.8%	26.8%	26.8%	33.8%	9.9%
I finish my physics assignments on time	0	4	16	32	19
	0.0%	5.6%	22.5%	45.1%	26.8%
I look forward to physics class with anticipation	2	4	16	38	11
	2.8%	5.6%	22.5%	53.5%	15.5%
With my friends, I discuss about physics	0	0	11	38	22
	0.0%	0.0%	15.5%	53.5%	31.0%

Table 5 shows that the theme related to enthusiasm toward physics revealed a generally positive attitude among participants. A significant majority expressed appreciation for learning about physical occurrences and their descriptions, with 91.6% showing some level of agreement. There was a notable fraction (31%) finding it worthwhile to study physics issues in more detail, although 45.1% expressed disagreement. Practical experimentation in a lab was seen as confidence-boosting by 93.0% of respondents. The importance of a foundational understanding of physics was highlighted by 90.1% agreeing that everyone benefited from it. While a substantial 71.8% found studying physics to be somewhat tedious, only 8.4% strongly agreed. Motivation for additional experiments was evident in 76.0% of participants, indicating a positive inclination toward practical application. Preferences for theory over practical work varied, with 60.6% expressing some level of agreement. Good time management was reported by 72.0% in finishing physics assignments on time. Positive anticipation for physics class was expressed by 69.0% of respondents. Social engagement was evident, with 84.5% reporting discussions about physics with friends.

Furthermore, the graph below illustrated the results of the attitude test in terms of enthusiasm towards physics for the control group. This visual representation served as an illustrative tool, capturing the collected data and providing a comprehensive overview of the experimental group's levels of enthusiasm for the subject.

Figure 5

Attitude Test in terms of enthusiasm toward physics for Control Group



The analysis of participants' enthusiasm toward physics revealed a generally positive attitude. Practical experimentation in a lab was seen as confidence-boosting, and there was agreement on the importance of a foundational understanding of physics. While some found studying physics somewhat tedious, overall sentiment was positive, with motivation for additional experiments and positive anticipation for physics class. Social engagement through discussions about physics with friends was also noted.

Table 6

Attitude Test for Control group (N =71) in terms of Physics Learning

Factor II: Physics Learning	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
In regards to my responses to the physics class questions, I am really happy and satisfied	0	0	14	37	20
	0.0%	0.0%	19.7%	52.1%	28.2%
Physics lab work increases individual productivity	0	1	11	35	24
	0.0%	1.4%	15.5%	49.3%	33.8%
I continue to practice the class problems until I master them	0	4	16	40	11
	0.0%	5.6%	22.5%	56.3%	15.5%
In my physics lesson, I feel under pressure	9	31	21	8	2
	12.7%	43.7%	29.6%	11.3%	2.8%
Understanding of physics is effectively achieved when students actively participate in both theory and practical lessons	0	3	10	26	32
	0.0%	4.2%	14.1%	36.6%	45.1%
Problem with real-world situation due to lack of physics courses	7	10	26	21	7
	9.9%	14.1%	36.6%	29.6%	9.9%
I make an effort to relate the physics issue to real-world circumstances	0	1	28	40	2
	0.0%	1.4%	39.4%	56.3%	2.8%
Instead of tackling physics problems, I try to concentrate more on memorizing the laws and derivations from the textbook	0	13	20	24	14
	0.0%	18.3%	28.2%	33.8%	19.7%

Numerous physics scenarios are challenging to visualize	2	3	17	30	19
	2.8%	4.2%	23.9%	42.3%	26.8%
It is extremely difficult to pass a physics exam without referring to notes or external aids.	20	26	11	9	5
	28.2%	36.6%	15.5%	12.7%	7.0%
I am not interested in challenging physics topics	7	26	24	10	4
	9.9%	36.6%	33.8%	14.1%	5.6%
I'm forced to study physics by my parents and my teacher	18	15	19	9	10
	25.4%	21.1%	26.8%	12.7%	14.1%
I only study physics when it's time for an exam	21	31	9	7	3
	29.6%	43.7%	12.7%	9.9%	4.2%
It's beyond my capacity to learn physics	15	19	14	15	8
	21.1%	26.8%	19.7%	21.1%	11.3%

Table 6 highlights the theme associated with physics learning, offering valuable insights into the participants' attitudes and experiences with physics education. A majority of respondents, totaling 52.1%, expressed happiness and satisfaction with their responses to physics class questions, indicating a positive overall sentiment. Additionally, 83.1% believed that physics lab work enhanced individual productivity. Active engagement in problem-solving was prevalent, with 71.8% practicing class problems until mastery was achieved. However, a notable 56.3% felt under pressure during physics lessons. The data underscored the importance of active participation in both theoretical and practical lessons, with 81.7% agreeing that effective understanding of physics was achieved through such engagement. A concerning aspect was highlighted, as 50.7% of participants found it challenging to visualize numerous physics scenarios. Academic integrity emerged as a notable concern, as 64.8% of participants expressed the belief that passing a physics exam without relying on external aids or notes was extremely difficult. Furthermore, 43.7% admitted to being forced to study physics by parents and teachers, and 73.3%

revealed studying physics only when it was time for an exam. Lastly, 48.2% found certain physics topics uninteresting, and 47.3% felt that learning physics was beyond their capacity. The findings suggested a mix of positive engagement, academic pressure, and challenges in visualization and motivation within the context of physics learning.

Physics learning revealed a complex landscape of attitudes and experiences among participants. While a majority expressed happiness and satisfaction with their physics class responses, there were notable challenges. Participants largely acknowledged the productivity-enhancing nature of physics lab work and emphasized active problem-solving. However, a significant portion felt under pressure during physics lessons, and visualization of certain scenarios proved challenging for over half of the respondents. Academic integrity was a concern, with many finding it challenging to pass exams without using cheat sheets. Additionally, a considerable number felt forced to study physics and admitted to studying only during exam periods. There was also a noteworthy proportion finding certain physics topics uninteresting, and a significant percentage perceived physics learning as beyond their capacity.

Table 7

Attitude Test for Control group (N =71) in terms of Physics as a Process

Factor III: Physics as a Process	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
Physics is a subject that is always changing	0	4	23	27	17
	0.0%	5.6%	32.4%	38.0%	23.9%
Physics is a process for acquiring knowledge, not just a body of knowledge	1	0	3	34	33
	1.4%	0.0%	4.2%	47.9%	46.5%
	9	26	17	14	5

The laws that have already been discovered do not require further verification	12.7%	36.6%	23.9%	19.7%	7.0%
The truth of the laws of physics might no longer hold true tomorrow due to the rapid advancement of scientific knowledge	4	11	28	13	15
	5.6%	15.5%	39.4%	18.3%	21.1%
There will eventually be a discovery of all physics laws	3	12	23	26	7
	4.2%	16.9%	32.4%	36.6%	9.9%
In order to improve civilization and society, physics is crucial	0	6	12	26	27
	0.0%	8.5%	16.9%	36.6%	38.0%
Physics is all about memorization of rules and formulas; it lacks creativity	10	20	19	11	11
	14.1%	28.2%	26.8%	15.5%	15.5%
Science and other subjects have benefited immensely from the study of physics	0	0	4	33	34
	0.0%	0.0%	5.6%	46.5%	47.9%
Physics trains the mind and fosters critical thinking in students	0	1	5	28	37
	0.0%	1.4%	7.0%	39.4%	52.1%
Building a physics lab requires a substantial amount of infrastructure in order to comprehend the field	0	10	16	32	13
	0.0%	14.1%	22.5%	45.1%	18.3%

The survey data on Factor III, which focused on physics as a process, revealed diverse perspectives among respondents. A substantial majority (61.9%) acknowledged the dynamic nature of physics, believing it was a subject that was always changing. Furthermore, an overwhelming majority (94.4%) highlighted that physics is not solely a body of knowledge but a dynamic process of knowledge acquisition. There was a significant divide regarding the need for further verification of already discovered laws, with 49.3% indicating that such verification was necessary. Respondents also expressed uncertainty (39.4%) about the stability of the laws of physics in the face of rapid scientific advancements. Additionally, opinions were divided on the eventual discovery of all physics laws (46.5% agreed). The majority (74.6%) agreed that physics played a crucial role in improving civilization and society. However, there was a notable split regarding whether physics was characterized by creativity or memorization, and a substantial consensus (94.4%) recognized the immense benefits physics brought to science and other subjects. Furthermore, an overwhelming majority (90.1%) affirmed that physics contributed to training the mind and fostering critical thinking in students. Lastly, there was agreement (63.4%) that building a physics lab required substantial infrastructure for a comprehensive understanding of the field.

The analysis of Factor III, which centered on physics as a process, revealed diverse perspectives among respondents. A majority acknowledged the dynamic nature of physics and believed it to be a continuous process for acquiring knowledge. Views differed on the need for further verification of discovered laws, stability of physics laws, and the eventual discovery of all physics laws. There was a notable split on whether physics involved creativity or memorization. However, there was a strong consensus on the substantial benefits of physics to science and other subjects, its role in improving civilization, and its contribution to mental training and critical thinking in students. The need for substantial infrastructure for a detailed comprehension of the field, particularly in the context of building a physics lab, was also recognized by a majority of respondents.

Table 8

Attitude Test for Control group (N =71) in terms of Physics Teacher

Factor IV: Physics Teacher	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
My physics teacher makes me nervous	38	21	6	2	4
	53.5%	29.6%	8.5%	2.8%	5.6%
	20	21	9	14	7

My physics teacher consistently gives the students too many assignments	28.2%	29.6%	12.7%	19.7%	9.9%
Problem-solving is encouraged by my physics teacher	2	1	3	33	32
	2.8%	1.4%	4.2%	46.5%	45.1%
The numerical problems regarding with a physics topic covered in class are rarely discussed by my physics teacher	8	29	10	11	13
	11.3%	40.8%	14.1%	15.5%	18.3%
My physics teacher regularly attends class every time	2	7	9	23	30
	2.8%	9.9%	12.7%	32.4%	42.3%
My physics teacher discourages students from addressing questions in class	13	37	13	5	3
	18.3%	52.1%	18.3%	7.0%	4.2%
My physics teacher doesn't explain the material in the lesson in a coherent manner	11	32	8	15	5
	15.5%	45.1%	11.3%	21.1%	7.0%
During class, my physics teacher employs a variety of teaching strategies	2	4	22	35	8
	2.8%	5.6%	31.0%	49.3%	11.3%
My physics teacher frequently conducts lessons in a lecture method	3	12	24	26	6
	4.2%	16.9%	33.8%	36.6%	8.5%
My physics teacher takes the necessary time to explain physics concepts to me	0	4	14	36	17
	0.0%	5.6%	19.7%	50.7%	23.9%
My physics teacher doesn't think I can learn	22	25	13	9	2
	31.0%	35.2%	18.3%	12.7%	2.8%
My physics teacher often loses patience with me	18	28	14	7	4
	25.4%	39.4%	19.7%	9.9%	5.6%
My physics teacher places a strong emphasis on comprehension rather than rote learning	3	8	13	33	14
	4.2%	11.3%	18.3%	46.5%	19.7%
In the future, I want to be a physics teacher	3	11	19	27	11
	4.2%	15.5%	26.8%	38.0%	15.5%

The responses in Factor IV, which pertained to perceptions of the physics teacher, provided insights into students' experiences. The majority (53.5%) reported feeling more aware and attentive while their physics teacher was around., while a significant portion (29.6%) believed the teacher assigned too many tasks consistently. The teacher's consistent attendance in class (32.4% agreed and 42.3% strongly agreed) and promotion of problem-solving (46.5% agreed and 45.1% strongly agreed) were advantageous traits. However, a sizable portion (52.1%) stated that they would rather look for alternate methods to get their problems answered than ask inquiries directly, and there were mixed views on the coherence of lesson explanations. Teaching methods varied, with a preference for diverse strategies (31.0% agreed and 49.3% strongly agreed) over frequent use of the lecture method (36.6%). While a majority (50.7%) believed the teacher took the necessary time to explain concepts, a notable percentage (35.2%) felt the teacher did not think they could learn. Patience was a concern for some, with 25.4% feeling the teacher often lost patience. On a positive note, a significant percentage (46.5%) believed the teacher emphasized comprehension over rote learning. Looking ahead, a notable portion (38.0%) expressed an interest in becoming a physics teacher in the future.

The analysis of Factor IV, focused on perceptions of the physics teacher, provided valuable insights into students' experiences. The majority of students expressed feelings of nervousness with their physics teacher and noted concerns about the frequency of assigned tasks. Positive aspects included the encouragement of problem-solving and the teacher's consistent attendance in class. However, challenges surfaced regarding students feeling discouraged from asking questions, mixed views on lesson explanations, and varying preferences for teaching methods. While a significant percentage believed the teacher emphasized comprehension, concerns about patience and doubts about the teacher's belief in students' learning abilities were also noted. Interestingly, a notable portion expressed an interest in pursuing a career as a physics teacher in the future.

Table 9

Attitude Test for Control group (N =71) in terms of Physics as a Future Vocation

Factor V: Physics as a Future Vocation	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
Being a physicist involves very little professional progression	5	12	20	24	10
	7.0%	16.9%	28.2%	33.8%	14.1%
Studying physics requires a lot of tolerance and patience	2	5	11	39	14
	2.8%	7.0%	15.5%	54.9%	19.7%
A physicist's progress is relatively slow	0	19	28	18	6
	0.0%	26.8%	39.4%	25.4%	8.5%
Jobs opportunities in physics are scarce	3	23	16	16	13
	4.2%	32.4%	22.5%	22.5%	18.3%
A very committed person working to better society is a physicist	0	4	13	41	13
	0.0%	5.6%	18.3%	57.7%	18.3%
There is a lack of creativity in the field of physics	3	29	14	16	9
	4.2%	40.8%	19.7%	22.5%	12.7%
A physicist spends their entire life doing experiments	1	5	26	29	10
	1.4%	7.0%	36.6%	40.8%	14.1%
Higher-level physics study leads to a bright future	0	4	15	28	24
	0.0%	5.6%	21.1%	39.4%	33.8%
Since none of their research has any applicability in the real world, physicists waste public money	10	26	23	9	3
	14.1%	36.6%	32.4%	12.7%	4.2%
In general, physicists are socially isolated	7	16	26	14	8
	9.9%	22.5%	36.6%	19.7%	11.3%

Factor V investigated opinions about physics as a potential career path. The information indicated that respondents' opinions on physics were not all the same. Even while a sizable percentage (33.8%) thought that physics will lead to a bright future, there were worries about career advancement, with 28.2% saying that there was very little advancement involved in being a physicist. Tolerance and patience were considered essential in physics, with a significant majority (54.9%) agreeing that studying physics required these qualities. There was a perception of relatively slow progress in a physicist's career, as indicated by 39.4% of respondents. Job opportunities in physics were perceived as scarce by a substantial portion (32.4%). On a positive note, a majority (57.7%) saw a physicist as a very committed person working to better society. However, concerns about creativity in the field were raised, with 40.8% expressing a belief that there was a lack of creativity in physics. Additionally, there were varying views on whether physicists spent their entire lives doing experiments. While 40.8% agreed with this statement, others disagreed. The applicability of physics research in the real world was questioned by 32.4%, believing that physicists wasted public money. Lastly, there were mixed perceptions about the social aspect of physicists, with 36.6% thinking that, in general, physicists were socially isolated.

Respondents varied in their views on physics as a future vocation. Some believed studying physics leads to a bright future, while others expressed concerns about limited professional progression and perceived job opportunities as scarce. Tolerance and patience were considered essential, but there was a perception of slow career progress. Respondents had mixed views on the creativity in physics and doubted the applicability of physics research in the real world. While many saw physicists as committed to societal betterment, opinions on social isolation among physicists were divided.

Analysis of Attitude Test for Experimental Group

Table 10

Attitude Test for Experimental group (N =95) in terms of Enthusiasm toward Physics

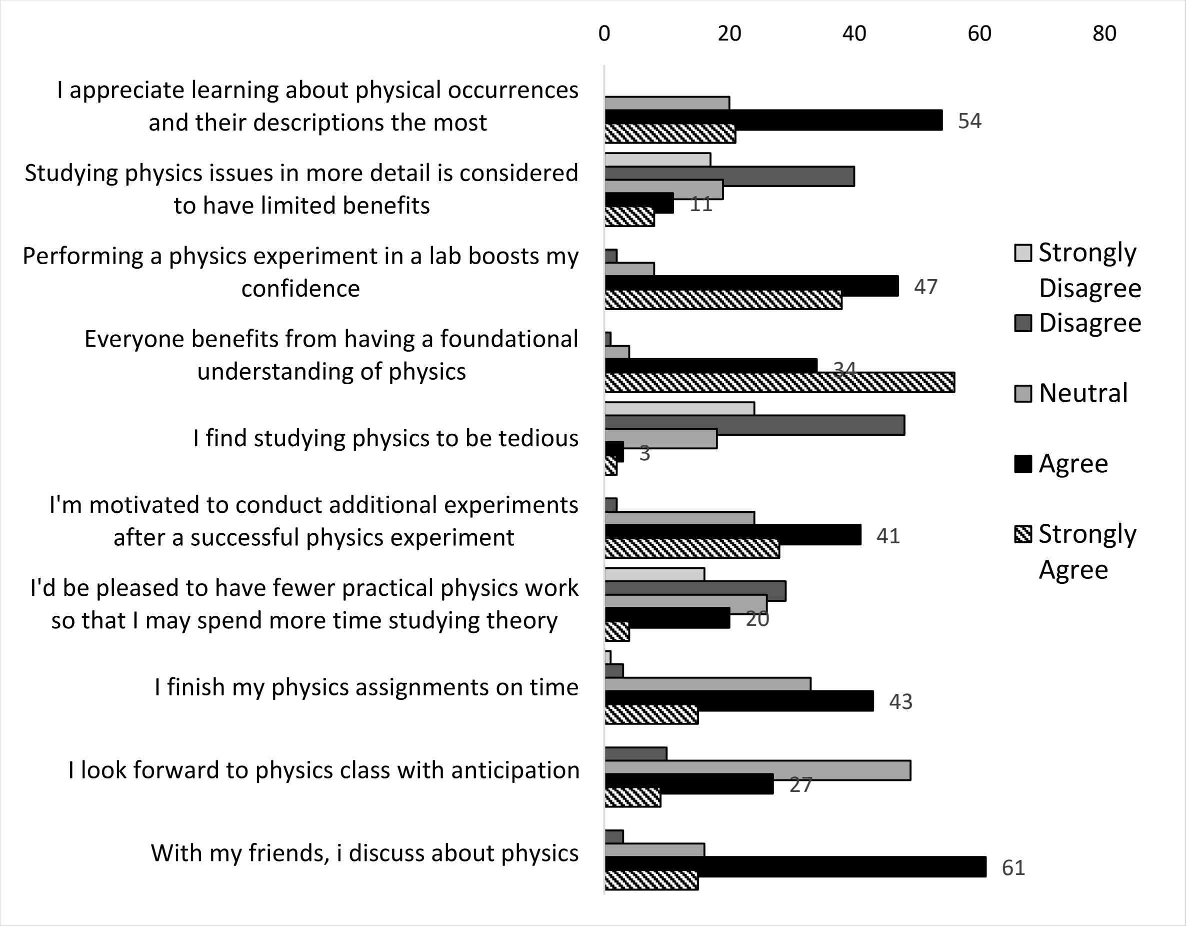
Factor I: Enthusiasm toward Physics	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
I appreciate learning about physical occurrences and their descriptions the most	0	0	20	54	21
	0.0%	0.0%	21.1%	56.8%	22.1%
It is not worthwhile to study physics issues in more detail	17	40	19	11	8
	17.9%	42.1%	20.0%	11.6%	8.4%
Performing a physics experiment in a lab boosts my confidence	0	2	8	47	38
	0.0%	2.1%	8.4%	49.5%	40.0%
Everyone benefits from having a foundational understanding of physics	0	1	4	34	56
	0.0%	1.1%	4.2%	35.8%	58.9%
I find studying physics to be tedious	24	48	18	3	2
	25.3%	50.5%	18.9%	3.2%	2.1%
I'm motivated to conduct additional experiments after a successful physics experiment	0	2	24	41	28
	0.0%	2.1%	25.3%	43.2%	29.5%
I'd be pleased to have fewer practical physics work so that I may spend more time studying theory	16	29	26	20	4
	16.8%	30.5%	27.4%	21.1%	4.2%
I finish my physics assignments on time	1	3	33	43	15
	1.1%	3.2%	34.7%	45.3%	15.8%
I look forward to physics class with anticipation	0	10	49	27	9
	0.0%	10.5%	51.6%	28.4%	9.5%
With my friends, i discuss about physics	0	3	16	61	15
	0.0%	3.2%	16.8%	64.2%	15.8%

The Attitude Test results for the Experimental group, which focused on Enthusiasm toward Physics, portrayed a spectrum of perspectives among respondents. A substantial majority expressed a strong appreciation for learning about physical occurrences and their descriptions, with over 78% in agreement (56.8% strongly agreed and 21.1% agreed). However, there was notable disagreement regarding the worthiness of studying physics issues in more detail, with 59.1% expressing disagreement (17.9% strongly disagreed and 42.1% disagreed). The majority strongly agreed that performing physics experiments boosted confidence, while a significant consensus recognized the benefits of having a foundational understanding of physics. Interestingly, a substantial portion found studying physics to be tedious, with 76.2% expressing agreement (25.3% strongly agreed and 50.5% agreed). Despite this, there was strong motivation to conduct additional experiments and anticipation for physics class, as indicated by 72.7% and 80.0% agreement, respectively. Moreover, a majority enjoyed discussing physics with friends, with 79.0% in agreement (64.2% strongly agreed and 15.8% agreed). These diverse responses reflected the multifaceted nature of the experimental group's attitudes and enthusiasm towards various aspects of physics education.

Moreover, the graph presented below depicted the outcomes of the enthusiasm-related attitude test conducted within the experimental group. This visual depiction served as an illustrative instrument, encapsulating the gathered data and offering a thorough overview of the experimental group's degree of enthusiasm for the subject.

Figure 6

Attitude Test in terms of enthusiasm toward physics for Experimental Group



The Attitude Test results for the Experimental group, focusing on Enthusiasm toward Physics, showcased a spectrum of perspectives. While a significant majority strongly appreciated learning about physical occurrences, there was notable disagreement about the worthiness of studying physics issues in more detail. Despite concerns about the tedious nature of studying, the majority expressed strong motivation for experiments and positive anticipation for physics class. Enjoying discussions about physics with friends was also a common sentiment.

Table 11

Attitude Test for Experimental group (N = 95) in terms of Physics Learning

Factor II: Physics Learning	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
In regards to my responses to the physics class questions, I am really happy and satisfied	0	1	23	50	21
	0.0%	1.1%	24.2%	52.6%	22.1%
Physics lab work increases individual productivity	1	2	7	41	44
	1.1%	2.1%	7.4%	43.2%	46.3%
I continue to practice the class problems until I master them	2	3	48	34	8
	2.1%	3.2%	50.5%	35.8%	8.4%
In my physics lesson, I feel under pressure	12	37	36	9	1
	12.6%	38.9%	37.9%	9.5%	1.1%
Understanding of physics is effectively achieved when students actively participate in both theory and practical lessons	0	0	3	30	62
	0.0%	0.0%	3.2%	31.6%	65.3%
Problem with real-world situation due to lack of physics courses	6	21	37	25	6
	6.3%	22.1%	38.9%	26.3%	6.3%
I make an effort to relate the physics issue to real-world circumstances	0	6	33	47	9
	0.0%	6.3%	34.7%	49.5%	9.5%
Instead of tackling physics problems, I try to concentrate more on memorizing the laws and derivations from the textbook	3	25	23	35	9
	3.2%	26.3%	24.2%	36.8%	9.5%
Numerous physics scenarios are challenging to visualize	0	4	17	52	22
	0.0%	4.2%	17.9%	54.7%	23.2%
It is exceedingly challenging to pass a physics exam without using a cheat sheet	23	31	24	12	5
	24.2%	32.6%	25.3%	12.6%	5.3%
I am not interested in challenging physics topics	9	33	30	17	6
	9.5%	34.7%	31.6%	17.9%	6.3%
I'm forced to study physics by my parents and my teacher	21	41	23	8	2
	22.1%	43.2%	24.2%	8.4%	2.1%
	12	46	23	12	2

I only study physics when it's time for an exam	12.6%	48.4%	24.2%	12.6%	2.1%
It's beyond my capacity to learn physics	25	39	20	9	2
	26.3%	41.1%	21.1%	9.5%	2.1%

Table 11 above for the attitude test for the experimental group, which focused on Physics Learning, revealed diverse attitudes and sentiments among the participants. A considerable majority expressed satisfaction and happiness with their responses to physics class questions, with over 74% in agreement (52.6% agreed and 22.1% strongly agreed). Additionally, a significant consensus believed that physics lab work enhanced individual productivity, with 89.5% expressing agreement (43.2% agreed and 46.3% strongly agreed). However, there was a mixed approach to practicing class problems, with 50.5% agreeing and 8.4% strongly agreeing. Some participants felt under pressure during physics lessons, with 38.9% strongly disagreeing. The majority strongly agreed that understanding physics was effectively achieved through active participation in both theory and practical lessons, constituting 96.9%. While participants made efforts to relate physics issues to real-world circumstances (84.2% agreed and 9.5% strongly agreed), some acknowledged challenges in visualizing numerous physics scenarios (54.7% agreed and 23.2% strongly agreed). A notable percentage found it challenging to pass a physics exam without using a cheat sheet (57.9% agreed and 5.3% strongly agreed). Additionally, there was diversity in interest levels in challenging physics topics, with 34.7% disagreeing. Some participants felt forced to study physics by their parents and teachers (43.2% agreed), and a significant portion studied physics only when exams approached (48.4%). Interestingly, a minority believed it was beyond their capacity to learn physics, with 26.3% agreeing. Overall, these results provided insights into the varied perspectives and approaches to physics learning within the Experimental group.

There was a range of interest levels in challenging physics topics, with some participants feeling obligated to study physics due to parental and teacher influence. Additionally, a substantial number focused on studying physics primarily when exams were imminent. Notably, a minority held the belief that learning physics was beyond their capacity. In summary, these findings offered valuable insights into the diverse perspectives and approaches to physics learning within the Experimental group.

Table 12

Attitude Test for Experimental group (N = 95) in terms of Physics as a Process

Factor III: Physics as a Process	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
Physics is a subject that is always changing	3	3	14	47	28
	3.2%	3.2%	14.7%	49.5%	29.5%
Physics is a process for acquiring knowledge, not just a body of knowledge	1	1	3	41	49
	1.1%	1.1%	3.2%	43.2%	51.6%
The laws that have already been discovered do not require further verification	16	30	26	19	4
	16.8%	31.6%	27.4%	20.0%	4.2%
The truth of the laws of physics might no longer hold true tomorrow due to the rapid advancement of scientific knowledge	7	17	24	33	14
	7.4%	17.9%	25.3%	34.7%	14.7%
There will eventually be a discovery of all physics laws	9	20	33	23	10
	9.5%	21.1%	34.7%	24.2%	10.5%
In order to improve civilization and society, physics is crucial	2	2	13	30	48
	2.1%	2.1%	13.7%	31.6%	50.5%
Physics is all about memorization of rules and formulas; it lacks creativity	24	48	11	8	4
	25.3%	50.5%	11.6%	8.4%	4.2%
	1	1	3	31	59

Science and other subjects have benefited immensely from the study of physics	1.1%	1.1%	3.2%	32.6%	62.1%
Physics trains the mind and fosters critical thinking in students	0	2	5	46	42
	0.0%	2.1%	5.3%	48.4%	44.2%
Building a physics lab requires a substantial amount of infrastructure in order to comprehend the field	6	17	27	31	14
	6.3%	17.9%	28.4%	32.6%	14.7%

Table 12 revealed that the findings from the attitude test for the experimental group, which focused on Physics as a Process, illuminated diverse perspectives on various aspects of physics understanding. A substantial consensus acknowledged the dynamic nature of physics, with 79% expressing agreement (49.5% agreed and 29.5% strongly agreed). Furthermore, there was recognition that physics was not merely a static body of knowledge but a continuous process for acquiring knowledge, with 94.8% agreeing (43.2% agreed and 51.6% strongly agreed). However, there was a divide on the need for further verification of already discovered laws, with 63.6% expressing agreement (31.6% agreed and 27.4% strongly agreed). Participants also demonstrated uncertainty (43.1% agreed and 25.3% strongly agreed) about the stability of physics laws in the face of rapid scientific advancements. Views differed on the eventual discovery of all physics laws, with 65.2% expressing agreement (21.1% agreed and 34.7% strongly agreed). The majority emphasized the crucial role of physics in improving civilization and society (81.1% agreed), while opinions were divided on whether physics was characterized by creativity or memorization. There was strong agreement (92.6%) that science and other subjects had immensely benefited from the study of physics. Additionally, there was consensus (92.6%) that physics contributed to training the mind and fostering critical thinking in students. Finally, a majority (75.3%) agreed that building a physics lab necessitated a substantial amount of infrastructure for a comprehensive understanding of the field. These insights underscored the varied perceptions within the Experimental group regarding the dynamic nature, significance, and methodology of physics as a process.

Results from the experimental group's attitude test on physics as a process showed diverse perspectives. Participants acknowledged physics as a dynamic, continuous process for knowledge acquisition. Opinions varied on the need for further verification of laws and the stability of physics laws amid advancements. Views differed on the eventual discovery of all physics laws and whether physics was perceived as creative or memorization-oriented. The majority emphasized physics' crucial role in advancing civilization and agreed on its benefits to science and cognitive development. Additionally, most agreed that establishing a physics lab required substantial infrastructure.

Table 13

Attitude Test for Experimental group (N = 95) in terms of Physics Teacher

Factor IV: Physics Teacher	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
My physics teacher makes me nervous	28	30	29	8	0
	29.5%	31.6%	30.5%	8.4%	0.0%
My physics teacher consistently gives the students too many assignments	26	43	18	4	4
	27.4%	45.3%	18.9%	4.2%	4.2%
Problem-solving is encouraged by my physics teacher	0	5	4	60	26
	0.0%	5.3%	4.2%	63.2%	27.4%
The numerical problems regarding with a physics topic covered in class are rarely discussed by my physics teacher	38	26	5	18	7
	40.4%	27.7%	5.3%	19.1%	7.4%
My physics teacher regularly attends class every time	0	1	8	45	41
	0.0%	1.1%	8.4%	47.4%	43.2%
	42	44	7	1	1

My physics teacher discourages students from addressing questions in class	44.2%	46.3%	7.4%	1.1%	1.1%
My physics teacher doesn't explain the material in the lesson in a coherent manner	13	61	17	3	1
	13.7%	64.2%	17.9%	3.2%	1.1%
During class, my physics teacher employs a variety of teaching strategies	2	6	21	53	13
	2.1%	6.3%	22.1%	55.8%	13.7%
My physics teacher frequently conducts lessons in a lecture method	0	15	37	40	3
	0.0%	15.8%	38.9%	42.1%	3.2%
My physics teacher takes the necessary time to explain physics concepts to me	2	3	14	53	23
	2.1%	3.2%	14.7%	55.8%	24.2%
My physics teacher doesn't think I can learn	19	51	23	2	0
	20.0%	53.7%	24.2%	2.1%	0.0%
My physics teacher often loses patience with me	22	37	24	11	1
	23.2%	38.9%	25.3%	11.6%	1.1%
My physics teacher places a strong emphasis on comprehension rather than rote learning	2	7	10	52	24
	2.1%	7.4%	10.5%	54.7%	25.3%
In the future, I want to be a physics teacher	16	19	30	21	9
	16.8%	20.0%	31.6%	22.1%	9.5%

The Attitude Test results for the Experimental group, focusing on Physics Teacher, presented diverse perspectives. While a significant proportion felt encouraged by their physics teacher in problem-solving (63.2% strongly agreed) and acknowledged the teacher's regular attendance (47.4% strongly agreed), there were concerns about assignments, with 45.3% disagreeing that the teacher consistently gave too many. Participants expressed discomfort, as 29.5% strongly disagreed that their physics teacher made them nervous. There were mixed views on the coherence of lesson explanations, with 64.2% disagreeing. Interestingly, the majority believed the teacher took sufficient time to explain concepts (55.8% strongly agreed), but opinions diverged on the teacher's belief in students' learning abilities, as 53.7%

strongly disagreed. The use of diverse teaching strategies was well-received (55.8% strongly agreed), contrasting with a low preference for the lecture method (42.1% strongly disagreed). Despite concerns, 31.6% strongly agreed and 22.1% agreed that they aspired to become a physics teacher in the past. These nuanced insights underscored the varied experiences and perceptions within the Experimental group regarding their interactions with the physics teacher.

The attitude test results for the experimental group, focusing on physics teacher, highlighted diverse perspectives. While many felt encouraged in problem-solving and acknowledged regular attendance, concerns arose about assignment load. Some participants expressed discomfort with their physics teacher, and views on lesson coherence were mixed. Notably, there was confidence in the teacher's explanation of concepts, but opinions varied on the teacher's belief in students' learning abilities. Diverse teaching strategies were well-received, contrasting with a low preference for the lecture method. Despite concerns, a notable percentage aspired to become a physics teacher. These nuanced insights underscore the varied experiences and perceptions within the Experimental group regarding their interactions with the physics teacher.

Table 14

Attitude Test for Experimental group (N = 95) in terms of Physics as a Future Vocation

Factor V: physics as a future vocation	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
Being a physicist involves very little professional progression	6	33	38	15	3
	6.3%	34.7%	40.0%	15.8%	3.2%
Studying physics requires a lot of tolerance and patience	1	4	18	48	24
	1.1%	4.2%	18.9%	50.5%	25.3%
	1	34	38	19	3

A physicist's progress is relatively slow	1.1%	35.8%	40.0%	20.0%	3.2%
Jobs opportunities in physics are scarce	13	38	21	16	7
	13.7%	40.0%	22.1%	16.8%	7.4%
A very committed person working to better society is a physicist	0	8	19	50	18
	0.0%	8.4%	20.0%	52.6%	18.9%
There is a lack of creativity in the field of physics	15	34	27	15	4
	15.8%	35.8%	28.4%	15.8%	4.2%
A physicist spends their entire life doing experiments	3	19	27	37	9
	3.2%	20.0%	28.4%	38.9%	9.5%
Higher-level physics study leads to a bright future	1	4	21	52	17
	1.1%	4.2%	22.1%	54.7%	17.9%
Since none of their research has any applicability in the real world, physicists waste public money	21	48	22	3	1
	22.1%	50.5%	23.2%	3.2%	1.1%
In general, physicists are socially isolated	3	36	36	16	4
	3.2%	37.9%	37.9%	16.8%	4.2%

Table 14 revealed a range of perceptions focusing on physics as a future vocation in experimental group. Some participants expressed concerns about professional progression, with 40.0% disagreeing that being a physicist involves very little professional progression. There were mixed views on the level of tolerance and patience required in studying physics, with 50.5% agreeing. Opinions on a physicist's progress being relatively slow were divided, with 35.8% in disagreement. Job opportunities in physics were perceived as scarce by 40.0%. On a positive note, 52.6% agreed that a very committed person working to better society is a physicist. However, there were concerns about the lack of creativity in the field, with 35.8% agreeing. Views on a physicist spending their entire life doing experiments were diverse, with 38.9% agreeing. Higher-level physics study was seen as leading to a bright future by 54.7%. On a negative note, 50.5% agreed that physicists waste public money, and 37.9% believed physicists are socially isolated. These findings reflect the diverse attitudes within the Experimental group regarding the prospects and characteristics associated with a future in physics.

The experimental group's attitude test on physics as a future vocation revealed diverse perspectives. Concerns included professional progression and job opportunities, while there were mixed views on patience in studying physics and the pace of a physicist's progress. On a positive note, commitment to societal improvement was associated with physicists. Concerns arose about creativity, life spent on experiments, and perceived wastage of public money. Higher-level physics study was viewed positively, but beliefs about social isolation varied. These findings highlight diverse attitudes within the Experimental group regarding future prospects in physics.

Conclusion: *The preliminary attitude test toward physics, given to both the control and experimental groups prior to the intervention, revealed similar levels of readiness toward the subject. Statistical analysis indicated that both groups exhibited comparable enthusiasm for hands-on experimentation, challenges in visualizing abstract concepts, and varied motivation toward learning physics. This uniformity in initial attitudes suggests that both groups were equally prepared for physics education. The experimental group was subsequently introduced to the concept mapping method, while the control group continued with conventional instruction. These baseline findings provide a critical foundation for evaluating the impact of the respective teaching method.*

Test of normality for the data

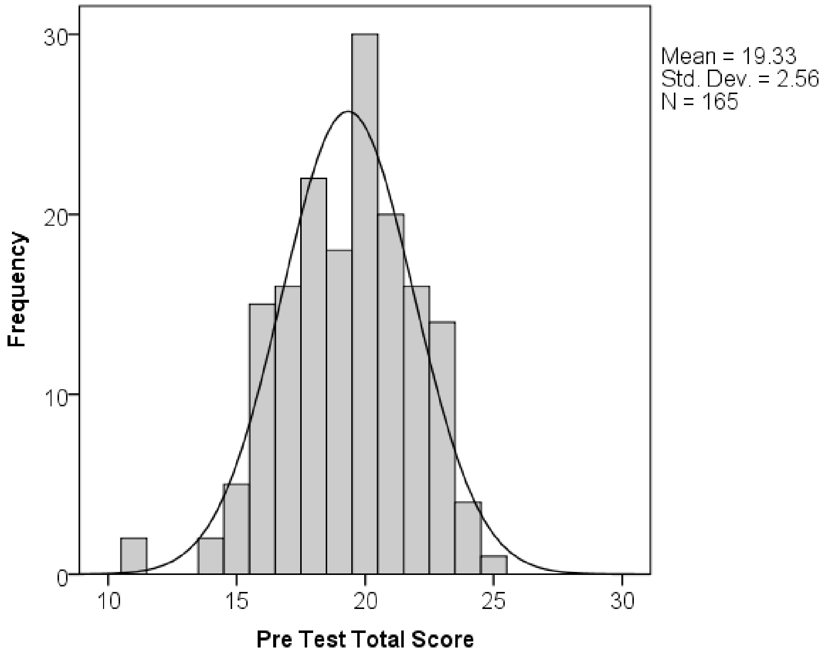
In the quantitative analysis, achievement scores were collected for the study. To test the normality of these scores, researcher analyzed the data using charts that plotted test scores against frequency, histograms, and Q-Q plots. These methods were used to test the null hypothesis that the data comes from a normal distribution.

Normal distribution curve of total achievement scores in pretest

In the presented histogram, the x-axis delineated the range of possible total scores, while the y-axis represented the frequency or count of participants, with N = 165, within each respective score range. The graphical depiction showcased a normal distribution pattern of total scores among the participants. The bell-shaped curve indicated that a majority of participants clustered around the mean score of 19.33, serving as a central tendency measure. The standard deviation, recorded as 2.56, highlighted the dispersion or variability in the scores around the mean. This visual representation allowed for a comprehensive examination of the normal distribution characteristics, providing insights into the spread and central tendency of the total scores achieved by the participants in the research study.

Figure 7

Normal distribution curve of total achievement scores in pretest

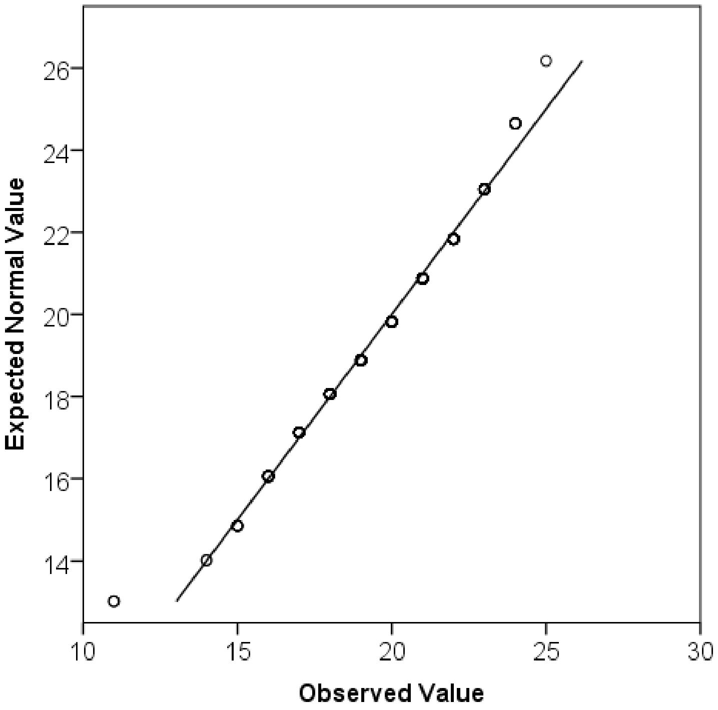


Normal Q-Q plot for the Pre-test Total scores

In the acquired Normal Q-Q plot for the Pre-test Total scores, the x-axis illustrated the observed values, while the y-axis represented the expected normal quantiles of the scores from the research participants. The data points formed a straight line, suggesting adherence to a normal distribution pattern. The mean, calculated as 19.33, served as the central tendency measure, indicating the average score. The standard deviation, with a value of 2.56, functioned as a measure of the spread or variability in the scores. This graphical representation facilitated the assessment of how well the observed scores matched the expected normal distribution. The alignment of data points along the straight line implied that the Pre-test Total scores exhibited a normal distribution, providing valuable insights into the statistical characteristics of the research data.

Figure 8

Normal Q-Q plot for the Pre-test Total scores

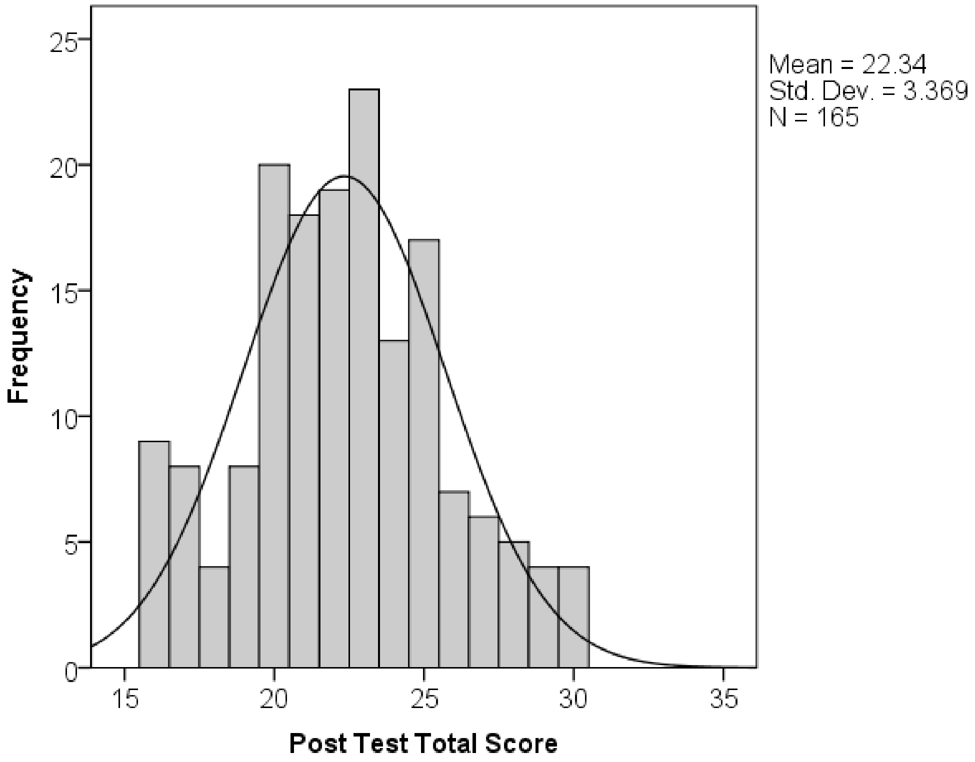


Normal distribution curve of total achievement scores in posttest

In the presented histogram for post-test total scores, the x-axis illustrated the range of possible total scores, while the y-axis represented the frequency or count of participants, with N = 165, within each respective score range. The graphical representation provided a clear overview of the distribution of total scores among the participants in the post-test phase, displaying a normal distribution pattern. The mean, calculated at 22.34, served as a central tendency measure, indicating the average score obtained. Furthermore, the standard deviation, recorded as 3.369, acted as a measure of the spread or variability in the scores. This normal distribution pattern, evident in the visual presentation, facilitated a thorough examination of the distribution, spread, and central tendency of the total scores achieved by the participants in the research study.

Figure 9

Normal distribution curve of total achievement scores in posttest

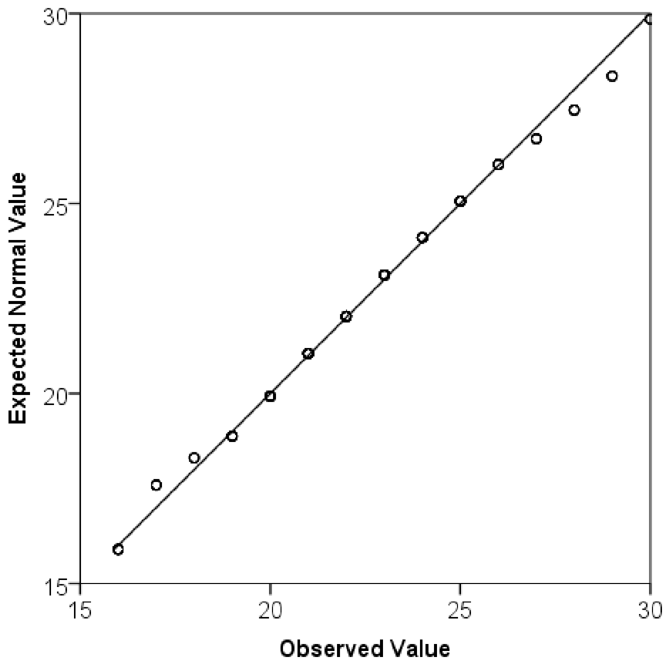


Normal Q-Q plot for the Post-test Total scores

In the obtained Normal Q-Q plot for the Post-test Total scores, the x-axis depicted the observed values, while the y-axis represented the expected normal quantiles of the scores from the research participants. The data points aligned in a straight line, indicating conformity to a normal distribution pattern. The mean, calculated at 22.34, acted as the central tendency measure, representing the average score. Additionally, the standard deviation, with a value of 3.369, served as a gauge of the spread or variability in the scores. This visual representation aided in evaluating how closely the observed scores adhered to the expected normal distribution. The linear arrangement of data points along the straight line suggested that the Post-test Total scores followed a normal distribution, offering valuable insights into the statistical characteristics of the research data.

Figure 10

Normal Q-Q plot for the Post-test Total scores



Analysis of Physics Achievement Test

The quantitative data were collected using Physics Achievement Tests (PAT) consisting of 40 test items, with 10 items assigned to each level of the cognitive domain for both the pretest and posttest administered to the experimental and control groups. The mean and standard deviation for both the pretest and posttest scores were calculated, overall and across the cognitive domains. Comparisons were conducted between the experimental and control groups, as well as between male and female students, using both descriptive and inferential statistics. A summary of the results and interpretations is provided in the following tables. At the start of the experiment, pretest scores were collected, and the mean, standard deviation, and t-scores (calculated using SPSS 20) are displayed in Table 15.

Table 15

Descriptive Statistics of Pre and Posttest of Experimental and Control Groups

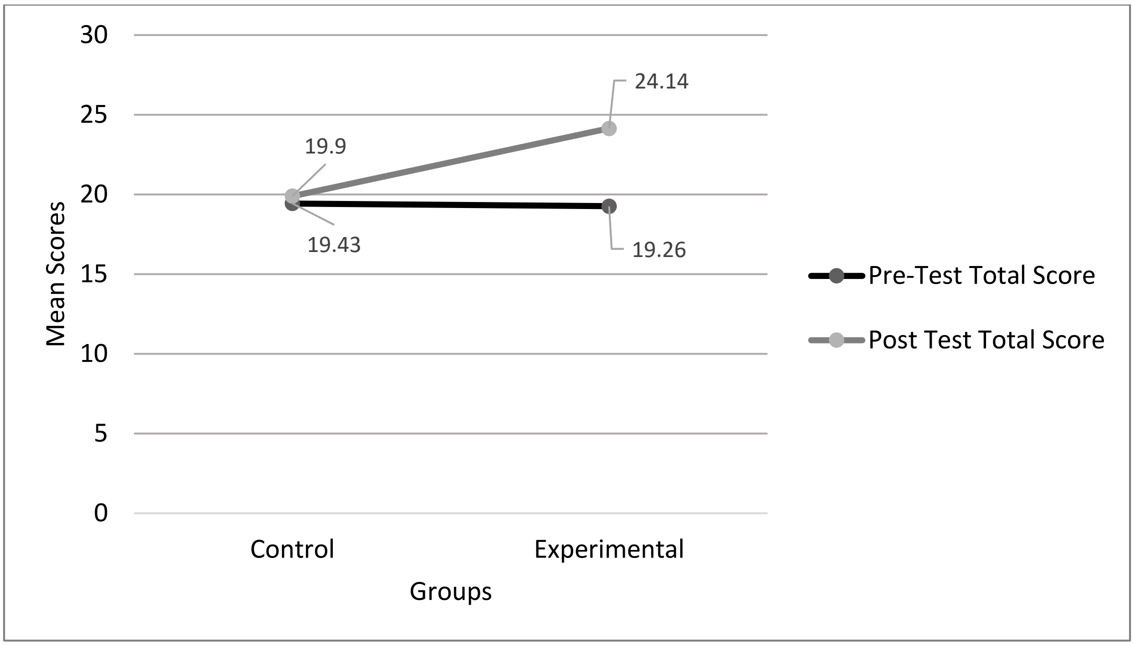
Test Scores	Control and Experimental	N	Mean	Std. Deviation	Std. Error Mean
Pre-Test Total Score	Control	70	19.43	2.405	.287
	Experimental	95	19.26	2.679	.275
Post Test Total Score	Control	70	19.90	2.329	.278
	Experimental	95	24.14	2.849	.292

Table 15 presents descriptive statistics for the pretest and posttest scores of both experimental and control groups. The pretest mean score for the control group (N=70) was 19.43, with a standard deviation of 2.405, and the experimental group (N=95) had a similar pretest mean of 19.26, with a standard deviation of 2.679. In the posttest, the control group's mean score slightly increased to 19.90 (SD = 2.329), while the experimental group, following the intervention, saw a significant improvement with a mean score of 24.14 (SD = 2.849). Both groups showed reliable estimates for their population means based on standard error values.

Furthermore, the graph below illustrated the mean scores of both the Control and Experimental groups on a Pre-Test and Post-Test.

Figure 11

Mean scores of Pre and Posttest of Experimental and Control Groups



The data from Table 15 and Figure 11 indicated that both groups had similar pre-test total scores, with the Control group having a slightly higher mean. However, after the intervention, the Experimental group showed a substantial improvement in their post-test scores, while the Control group's scores only showed a marginal increase.

To evaluate the experimental and control groups across each cognitive domain, the mean and standard deviation of the pretest and posttest scores were computed for each level of cognitive domain. So, descriptive statistics of both group in pretest were presented in table 16.

Table 16

Descriptive Statistics of Experimental and Control in Pretest

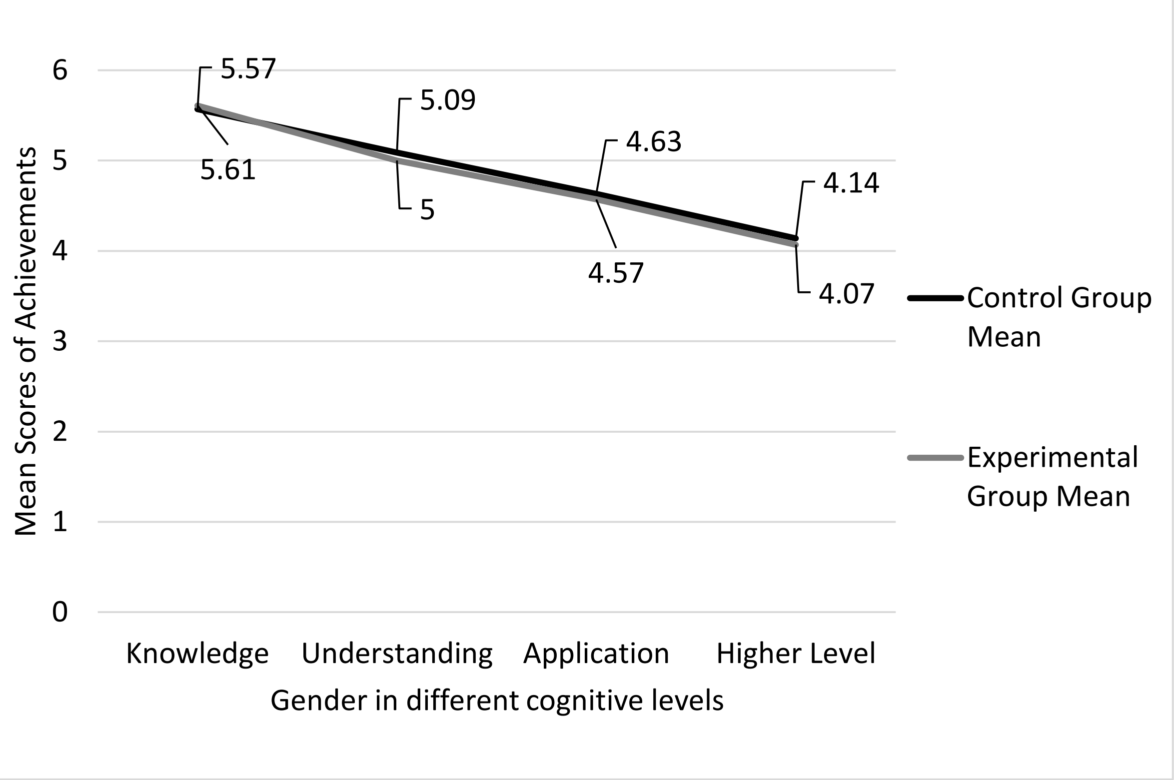
Level of Cognitive Domain	Groups	N	Mean	Std. Deviation
Knowledge	Control	70	5.57	1.314
	Experimental	95	5.61	1.299
Understanding	Control	70	5.09	1.189
	Experimental	95	5.00	1.042
Application	Control	70	4.63	1.364
	Experimental	95	4.57	1.318
Higher level	Control	70	4.14	1.133
	Experimental	95	4.07	1.240

The table 16 compared the descriptive statistics of two groups, the Control and Experimental groups, across different cognitive domains. In the Knowledge domain, the Experimental group (N=95) showed a slightly higher mean score (5.61) compared to the Control group (N=70) with a mean score of 5.57. Both groups displayed similar standard deviations (1.299 and 1.314, respectively). For the Understanding domain, the Control group (N=70) had a slightly higher mean score (5.09) than the Experimental group (N=95) with a mean score of 5.00. Again, the standard deviations for both groups were quite similar (1.189 and 1.042, respectively). In the Application domain, the Control group (N=70) had a marginally higher mean score (4.63) compared to the Experimental group (N=95) with a mean score of 4.57. Their standard deviations were also comparable (1.364 and 1.318, respectively). Lastly, in the Higher-level domain, the Control group (N=70) and the Experimental group (N=95) had mean scores of 4.14 and 4.07, respectively, with similar standard deviations (1.133 and 1.240, respectively). Overall, the differences in mean scores between the two groups across all cognitive domains were relatively small, and both groups displayed similar variability in their performance.

Similarly, the graph 12 below illustrated the mean scores of achievements in a Pre-test for the Experimental and Control groups across four categories.

Figure 12

Plot of mean scores of achievements of Experimental and Control group in Pre-test



The table compared the descriptive statistics of two groups, the Control and Experimental groups, across different cognitive domains. The results showed that in the Knowledge domain, the Experimental group had a slightly higher mean score than the Control group, with similar standard deviations. However, in the Understanding, Application, and Higher-level domains, the Control group had slightly higher mean scores compared to the Experimental group, with comparable standard deviations. Overall, both groups exhibited similar performance in the different cognitive domains, with only minor differences observed between them. From graph, overall, the Pre-test results indicated that there were minimal differences in mean scores between the Experimental and Control groups across all four achievement categories, with the

Experimental group holding a slight advantage in Knowledge and Understanding while trailing slightly in Application and Higher-Level skills.

Table 17

Group Statistics for Pre-Test Total Scores in Experimental and control Group

Test Score	Groups	N	Mean	Std. Deviation
Pre Test Total Score	Control	70	19.43	2.405
	Experimental	95	19.26	2.679

The table 17 showed that the pre-test scores for both the control and experimental groups were nearly identical, with the control group averaging 19.43 and the experimental group 19.26. The experimental group had slightly more variability, as indicated by a higher standard deviation of 2.679 compared to the control group's 2.405. Both groups had similar baseline performances before the intervention. However, to draw more robust conclusions and assess the statistical significance of the differences, further inferential statistical analysis (e.g., t-test or ANOVA) would be necessary.

Table 18

Independent Samples Test for Pre-Test Total Scores in Experimental and Control Group

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Pre-Test Total Score	Equal variances assumed	.175	.676	.409	163	.683	.165	.404
	Equal variances not assumed			.416	156.686	.678	.165	.398

The Independent Samples Test was conducted to compare two groups based on their pre-test total scores. Levene's Test for Equality of Variances indicated no statistically significant difference in the variances of the two groups' pre-test scores, whether equal variances were assumed (F=0.175, p=0.676) or not assumed (F=0.416, p=0.678). Additionally, the t-test for Equality of Means revealed no statistically significant difference in the means of the two groups' pre-test scores, whether equal variances were assumed (t=0.409, df=163, p=0.683) or not assumed (t=0.678, df=156.686, p=0.398). Consequently, there is no evidence to suggest a statistically significant difference between the two groups in terms of their pre-test total scores, irrespective of the assumption of equal variances.

The Independent Samples Test showed no significant difference in the pre-test total scores between the two groups, irrespective of equal variance assumptions (p > 0.05).

Table 19

Analysis of Variance for Experimental and Control Groups in Pretest

Level of Cognitive Domain		Sum of Squares	df	Mean Square	F	Sig.
Knowledge	Between Groups	.062	1	.062	.036	.849**
	Within Groups	277.732	163	1.704		
	Total	277.794	164			
Understanding	Between Groups	.296	1	.296	.242	.623**
	Within Groups	199.486	163	1.224		
	Total	199.782	164			
Application	Between Groups	.146	1	.146	.081	.776**
	Within Groups	291.648	163	1.789		
	Total	291.794	164			

Higher level	Between Groups	.193	1	.193	.135	.714**
	Within Groups	233.056	163	1.430		
	Total	233.248	164			

Note. * Significant, ** Not significant at 0.05 level of Significant

The analysis of variance (ANOVA) for the pretest scores across the cognitive domains—Knowledge, Understanding, Application, and Higher Level—shows no statistically significant differences between the Experimental and Control groups prior to the concept mapping intervention. In the Knowledge domain, the ANOVA yielded an F-value of 0.036 with a p-value of 0.849, indicating that the two groups had similar knowledge levels before the intervention. Likewise, the Understanding domain revealed no significant difference, with an F-value of 0.242 and a p-value of 0.623, suggesting that both groups were comparable in terms of their understanding. In the Application domain, the F-value was 0.081 with a p-value of 0.776, further indicating no meaningful distinction between the groups' ability to apply concepts before the intervention. Similarly, the Higher Level cognitive domain showed an F-value of 0.135 and a p-value of 0.714, confirming that the higher-order thinking skills of both groups were on par before the study began.

These results demonstrate that both the Experimental and Control groups started at an equivalent baseline in all cognitive domains, which is crucial for ensuring the validity of the posttest analysis. Since no significant differences existed between the groups prior to the intervention, any improvements in posttest scores can be confidently attributed to the concept mapping method, rather than pre-existing disparities between the groups. This equivalence in the pretest strengthens the reliability of the experimental study, providing a solid foundation for evaluating the effectiveness of concept mapping in enhancing students' cognitive performance.

Table 20

Descriptive Statistics of Experimental and Control in Posttest

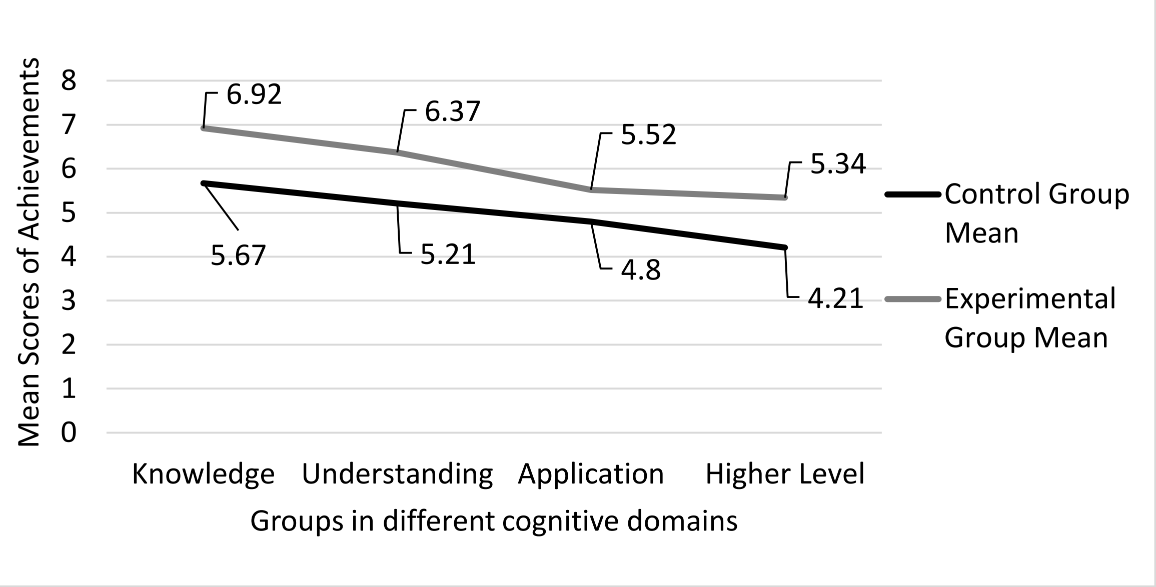
Level of Cognitive Domain	Groups	N	Mean	Std. Deviation
Knowledge	Control	70	5.67	1.327
	Experimental	95	6.92	1.318
Understanding	Control	70	5.21	1.203
	Experimental	95	6.37	1.321
Application	Control	70	4.80	1.281
	Experimental	95	5.52	1.320
Higher level	Control	70	4.21	1.102
	Experimental	95	5.34	1.268

The table 20 displays the descriptive statistics of the Experimental and Control groups in the posttest scores across various levels of cognitive domains. In the Posttest of Knowledge, the Experimental group (N=95) demonstrated a significantly higher mean score (6.92) compared to the Control group (N=70) with a mean score of 5.67, as supported by the considerable difference and small standard deviations (1.318 and 1.327, respectively). Similarly, in the Posttest of Understanding and Posttest of Application, the Experimental group (N=95) outperformed the Control group (N=70) with higher mean scores (6.37 > 5.21, 5.52 > 4.80, respectively). The results were consistent across these domains, as the standard deviations for both groups were quite comparable. Additionally, in the Posttest of Higher level, the Experimental group (N=95) achieved a significantly higher mean score (5.34) than the Control group (N=70) with a mean score of 4.21, indicating a notable difference and relatively small standard deviations (1.268 and 1.102, respectively).

Similarly, in the Post-test, the graph 13 also depicted the mean scores of achievements for both the Experimental and Control groups across four categories.

Figure 13

Plot of mean scores of achievements of Experimental and Control group in Post-test



The Experimental group outperformed the Control group in all cognitive domains during the posttest assessment, with significantly higher mean scores observed in Knowledge (6.92 > 5.67), Understanding (6.37 > 5.21), Application (5.52 > 4.80), and Higher level (5.34 > 4.21). Overall, the Post-test results highlighted a significant positive impact of the intervention on the Experimental group's performance, as they consistently outperformed the Control group across all four achievement categories.

It is needed to test the difference that was found in descriptive Table 19 was significant or not. The following Table 21 the Independent Samples Test for Post-Test Total Scores in Experimental and Control Group were analyzed for more inferential results.

Table 21

Independent Samples Test for Post-Test Total Scores in Experimental and Control Group

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Post Test Total Score	Equal variances assumed	2.104	.149	-10.182	163	.000	-4.237	.416
	Equal variances not assumed			-10.495	161.199	.000	-4.237	.404

The Independent Samples Test compared two groups based on their post-test total scores. The Levene's Test showed no significant difference in variances for both equal variances assumed (F=2.104, p=0.149) and not assumed (F=-10.495, p = 0.000). However, the t-test for Equality of Means revealed a highly significant difference in means for both equal variances assumed (t=-10.182, df=163, p=0.000) and not assumed (t=-10.495, df=161.199, p=0.000). The mean difference was -4.237, indicating the second group scored approximately 4.237 points lower in the post-test compared to the first group. Therefore, the analysis suggests a statistically significant difference in the post-test total scores between the two groups.

The Independent Samples Test found a significant difference in post-test total scores between the two groups ($p < 0.001$). The second group scored approximately 4.237 points lower than the first group.

Conclusion: *The Independent Samples Test for pre-test and post-test total scores indicated no statistically significant difference between the experimental and control* *groups in the pre-test, confirming both groups were comparable before the intervention. However, a significant difference was observed in the post-test results, with the experimental group achieving notably higher scores than the control group. This suggests that the concept mapping intervention had a significant positive effect on the experimental group's performance, highlighting its effectiveness compared to the conventional method used in the control group.*

Again, it was needed to analyzed the difference more prominently. So, the following Table 22 the analysis of variance in experimental and control groups in posttest were analyzed.

Table 22

Analysis of Variance for Experimental and Control Groups in Posttest

Level of Cognitive Domain		Sum of Squares	df	Mean Square	F	Sig.
Knowledge	Between Groups	62.407	1	62.407	35.721	.000*
	Within Groups	284.769	163	1.747		
	Total	347.176	164			
Understanding	Between Groups	53.685	1	53.685	33.160	.000*
	Within Groups	263.891	163	1.619		
	Total	317.576	164			
Application	Between Groups	20.649	1	20.649	12.154	.001*
	Within Groups	276.926	163	1.699		
	Total	297.576	164			
Higher level	Between Groups	50.787	1	50.787	35.226	.000*
	Within Groups	235.007	163	1.442		
	Total	285.794	164			

Note. * Significant, ** Not significant at 0.05 level of Significant

The table 22 presents the results of an Analysis of Variance (ANOVA) conducted on the Experimental and Control groups in the posttest scores across different cognitive domains with concept mapping as the intervention. The ANOVA indicates significant differences between the groups in all cognitive domains (p<0.001 for Knowledge, Understanding, and Higher level; p=0.001 for Application). For the Posttest of Knowledge, the between-groups variability (Sum of Squares = 62.407) was much higher than the within-groups variability (Sum of Squares = 284.769), indicating that the concept mapping intervention had a substantial impact on the results. The same pattern is observed for the Posttest of Understanding (Between Groups: 53.685, Within Groups: 263.891), Posttest of Application (Between Groups: 20.649, Within Groups: 276.926), and Posttest of Higher level (Between Groups: 50.787, Within Groups: 235.007).

Concept mapping intervention significantly contributed to the improved performance of the Experimental group compared to the Control group in all cognitive domains, demonstrating its effectiveness as an instructional strategy.

After the ANOVA results, I further examined the impact by calculating Cohen's *d* to measure the effect size, determining the practical significance of the differences between the control and experimental groups.

Table 23

Analysis of effect sizes from Cohen's d calculation among Experimental and Control Groups in Pre and Posttest

Cognitive Level	t(df)	p-value	Mean Difference	Cohen’s d (Effect Size)
Knowledge	t(163) = 35.72	0.000	1.25	0.95 (Large)

Understanding	t(163) = 33.16	0.000	1.16	0.92 (Large)
Application	t(163) = 12.15	0.001	0.72	0.55 (Medium)
Higher Level	t(163) = 35.23	0.000	1.13	0.95 (Large)

Note: 0.2-0.5: Small effect size, 0.5-0.8: Medium effect size, 0.8+: Large effect size

The ANOVA results showed statistically significant differences between the control and experimental groups across all posttest categories: knowledge, understanding, application, and higher-level thinking, with p-values less than 0.05. To further examine the impact, Cohen's d was calculated to measure the effect size. The concept mapping method resulted in large effect sizes for both the knowledge (Cohen's d = 0.95) and understanding (Cohen's d = 0.92) levels, indicating substantial improvements in student achievement compared to the conventional method. The application level showed a medium effect size (Cohen's d = 0.55), reflecting moderate gains in students' ability to apply learned concepts. The higher-level cognitive domain also demonstrated a large effect size (Cohen's d = 0.95), confirming the strong effectiveness of the concept mapping method in enhancing higher-order thinking skills. These findings underscore that the concept mapping method not only led to significant statistical differences but also had a notable practical impact on students' cognitive achievements.

Furthermore, analysis of Post Hoc tests among cognitive level for multiple comparisons were analyzed using SPSS 20 as shown in table 24.

Table 24

Analysis of Post Hoc Tests among Cognitive Level for multiple comparisons

(I) Cognitive Level	(J) Cognitive Level	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Knowledge	Understanding	.53*	.106	.000	.26	.80
	Application	1.12*	.106	.000	.85	1.39
	Higher Level	1.52*	.106	.000	1.24	1.79
Understanding	Knowledge	-.53*	.106	.000	-.80	-.26
	Application	.59*	.106	.000	.32	.86
	Higher Level	.98*	.106	.000	.71	1.26
Application	Knowledge	-1.12*	.106	.000	-1.39	-.85
	Understanding	-.59*	.106	.000	-.86	-.32
	Higher Level	.39*	.106	.001	.12	.67
Higher Level	Knowledge	-1.52*	.106	.000	-1.79	-1.24
	Understanding	-.98*	.106	.000	-1.26	-.71
	Application	-.39*	.106	.001	-.67	-.12

Based on observed means.

The error term is Mean Square(Error) = 1.843.

*. The mean difference is significant at the .05 level.

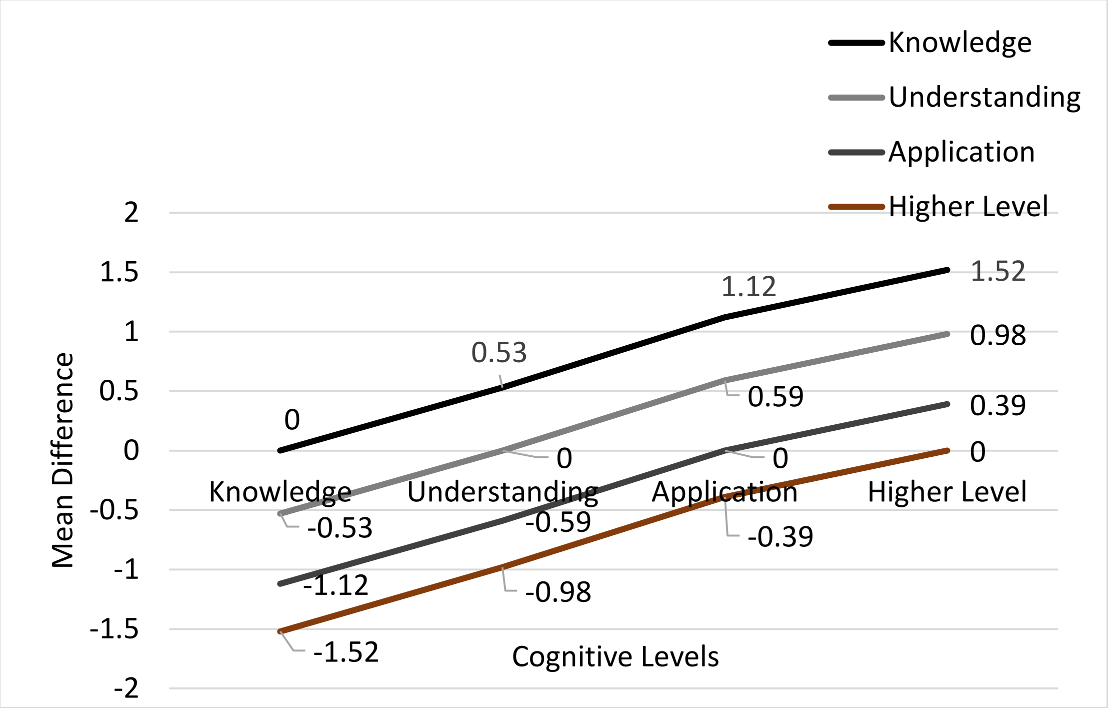
The Table 24 shows the analysis of post hoc tests provided compelling evidence regarding the effectiveness of the concept mapping method on student achievement across various cognitive levels. The Tukey HSD post hoc test demonstrated significant mean differences among cognitive levels, confirming that students achieved notably higher scores in Knowledge compared to Understanding (mean difference = 0.53, p = .000), Application (mean difference = 1.12, p = .000), and Higher Level (mean difference = 1.52, p = .000). This finding underscored the effectiveness of the concept mapping method in facilitating foundational knowledge acquisition, as students displayed strong performance in lower cognitive domains.

In addition, Understanding scores were significantly higher than those in both Application (mean difference = 0.59, p = .000) and Higher Level (mean difference = 0.98, p = .000), indicating that the concept mapping method also enhanced comprehension skills. However, the smallest mean difference was observed between Application and Higher Level (mean difference = 0.39, p = .001), suggesting that while students showed some ability to engage in higher-order thinking, they faced notable challenges when applying their knowledge in more complex contexts.

The line graph in figure 14 illustrated the mean differences in student achievement across various cognitive levels—Knowledge, Understanding, Application, and Higher Level—within the context of the concept mapping method. Analysis of the data revealed a progressive increase in mean differences as one moved from Knowledge to Higher Level, suggesting that the concept mapping approach effectively enhanced students' learning outcomes in foundational cognitive areas.

Figure 14

Plot of Post Hoc Tests among Cognitive Level for multiple comparisons



Specifically, the Knowledge level exhibited a mean difference of 0.53 when compared to Understanding, indicating a significant advantage for students in acquiring basic knowledge. This trend continued as Knowledge showed a mean difference of 1.12 in comparison to Application and a substantial difference of 1.52 when compared to Higher Level. These results confirmed that the concept mapping method facilitated the retention and understanding of factual knowledge, supporting students' initial learning stages.

Conversely, the Understanding level displayed mean differences of 0.59 when compared to Application and 0.98 when compared to Higher Level, underscoring the effectiveness of concept mapping in promoting comprehension. However, the negative mean differences observed between Application and Higher Level (−1.12 for Knowledge, −0.59 for Understanding, and −0.39 for Application) pointed to a notable decline in student performance as cognitive complexity increased. These results indicated that while students were able to engage with and retain lower-level knowledge and understanding effectively, they encountered challenges when transitioning to higher-order thinking tasks. Now the following Table 25 were tested the difference that existed in pretest was found significant or not?

Table 25

Analysis of correlations among various cognitive domains in post test

		Posttest of Knowledge	Posttest of Understanding	Posttest of Application	Posttest of Higher level
Knowledge	Pearson Correlation	1	.312**	.219**	.222**
	Sig. (2-tailed)		.000	.005	.004
	N	165	165	165	165
Understanding	Pearson Correlation	.312**	1	.144	.021
	Sig. (2-tailed)	.000		.065	.793
	N	165	165	165	165
Application	Pearson Correlation	.219**	.144	1	.041
	Sig. (2-tailed)	.005	.065		.603
	N	165	165	165	165
Higher level	Pearson Correlation	.222**	.021	.041	1
	Sig. (2-tailed)	.004	.793	.603	
	N	165	165	165	165

**. Correlation is significant at the 0.01 level (2-tailed).

The correlation table displays the Pearson correlation coefficients between the posttest scores of knowledge, understanding, higher level, and application. The posttest scores of knowledge show strong positive correlations with posttest scores of understanding ($r = 0.312$, $p < 0.01$) and higher level ($r = 0.222$, $p < 0.01$), as well as a moderate positive correlation with posttest scores of application ($r = 0.219$, $p < 0.01$). Posttest scores of understandings exhibit a moderate positive correlation with posttest scores of application ($r= 0.144$, $p < 0.05$), while the correlations between posttest scores of understanding or higher level with application are weak and not statistically significant ($p > 0.005$).

The results indicated notable positive relationships between the posttest scores, suggesting that students who performed well in one aspect of the posttest are likely to performed well in other aspects too, although the strength of the associations varies across the different pairs of post test scores.

Conclusion: *The results confirmed that the concept mapping method significantly influenced students' achievements in lower cognitive domains. However, a notable gap was identified in students' abilities to apply their knowledge and understanding to more complex cognitive tasks. The analysis revealed that students who excelled in one cognitive area often performed well in others, indicating some positive relationships among the different cognitive domains. Despite this, the varying strengths of these associations highlight the challenges students face in transitioning from knowledge and understanding to application and higher-order cognitive processes, such as critical thinking and real-world problem-solving. These findings emphasize the need for targeted interventions that build on the strengths fostered by concept mapping while addressing difficulties in higher-order thinking. By incorporating additional instructional strategies, educators can promote holistic student achievement and enhance students' capacities to engage effectively in higher-level cognitive tasks.*

To investigate whether there is a significant difference in achievement between male and female students at various cognitive levels when taught using the concept mapping method versus the conventional method, an analysis of the pre-test and post-test scores was conducted. The comparison focused on assessing cognitive performance across different domains, such as knowledge, comprehension, and application, for both teaching methods. Statistical tests, including t-tests and analysis of variance (ANOVA), were employed to determine whether gender played a significant role in student achievement and whether the concept mapping method had differential impacts on male and female students in terms of their cognitive development. The work involved is summarized in the following Tables.

Table 26

Analysis of pre-test scores obtained by gender regarding both campuses

Gender of Students	N	Mean	Std. Deviation	Std. Error Mean	df	t-value	Remarks
Male	67	19.46	2.648	.323	163	.593	.593>0.05
Female	98	19.24	2.508	.253			

The table 26 provides an analysis of pre-test scores obtained by gender for both sampled campuses. Male students (N = 67) had a mean score of 19.46, while female students (N = 98) had a mean score of 19.24. The t-value was 0.593 with 163 degrees of freedom, which corresponded to a p-value greater than 0.05, highlighting no significant difference in pre-test scores between male and female students.

The result of pre-test scores based on gender for both sampled campuses showed that there was no statistically significant difference between male and female students' performance. Both male and female students had similar average pre-test scores, suggesting that any observed differences in mean scores are not likely due to chance.

Table 27

Analysis of pre-test scores obtained by gender regarding control group

Gender of Students	N	Mean	Std. Deviation	Std. Error Mean	df	t-value	Remarks
Male	20	19.75	2.403	.537	68	.483	.483>0.05
Female	50	19.30	2.418	.342			

Table 27 presents the analysis of pre-test scores by gender within the control group. The control group included 20 male students with an average score of 19.75, a standard deviation of 2.403, and a standard error of the mean (SEM) of 0.537. There were 50 female students with an average score of 19.30, a standard deviation of 2.418, and a SEM of 0.342. An independent samples t-test yielded a t-value of 0.483 with 68 degrees of freedom. Since the p-value was greater than 0.05, there was no statistically significant difference in pre-test scores between male and female students in the control group.

The examination of pre-test scores within the control group based on gender revealed no statistically significant difference between male and female students. The observed variations in mean scores are likely due to chance, indicating that gender did not significantly influence the pre-test performance within the control group.

Table 28

Analysis of pre-test scores obtained by gender regarding experimental group

Gender of Students	N	Mean	Std. Deviation	Std. Error Mean	df	t-value	Remarks
Male	47	19.36	2.566	.374	93	.669	.669>0.05
Female	48	19.17	2.808	.405			

Table 28 presents an analysis of pre-test scores by gender in the experimental group. The male group (N=47) had a mean score of 19.36, with a standard deviation of 2.566 and a standard error of 0.374. The female group (N=48) had a mean score of

19.17, with a standard deviation of 2.808 and a standard error of 0.405. A t-test yielded a t-value of 0.669 with a p-value greater than 0.05, indicating no statistically significant difference in pre-test scores between male and female students in the experimental group.

The difference in mean pre-test scores between male and female students was not statistically significant, suggesting that any observed variations in scores may have occurred by chance rather than due to gender-related differences.

Table 29

Descriptive Statistics of the Achievement of Boys and Girls Students Pretest

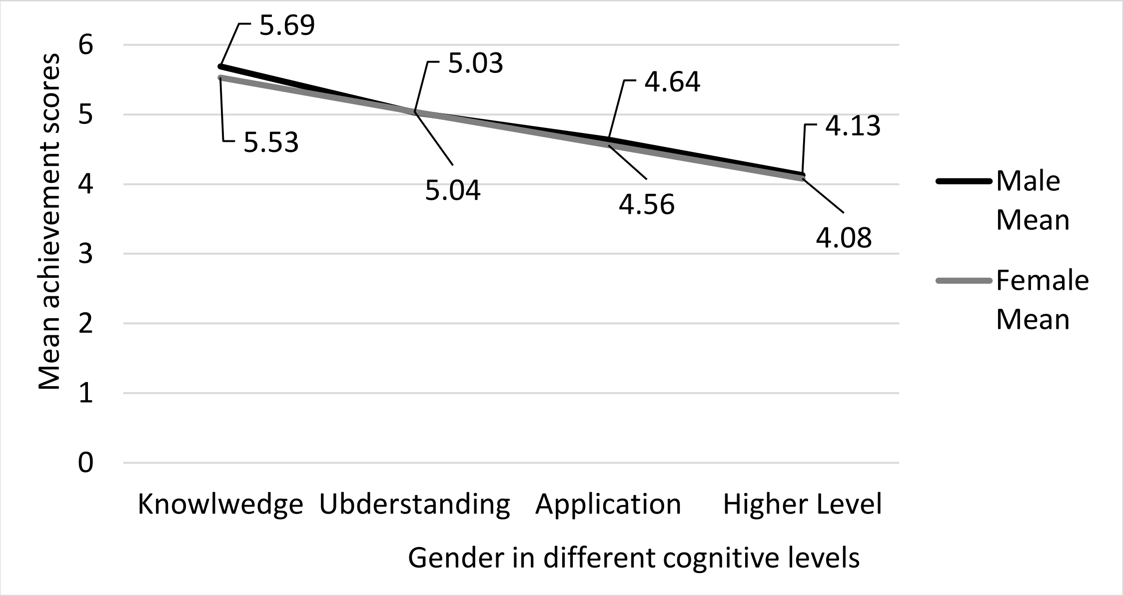
Level of Cognitive Domain	Gender of Students	N	Mean	Std. Deviation
Knowledge	Male	67	5.69	1.270
	Female	98	5.53	1.325
Understanding	Male	67	5.03	.937
	Female	98	5.04	1.209
Application	Male	67	4.64	1.422
	Female	98	4.56	1.277
Higher level	Male	67	4.13	1.153
	Female	98	4.08	1.224

The table 29 compared the achievement of male and female students across different levels of the cognitive domain. Male students scored 5.69 in the "Knowledge" domain, while female students scored slightly lower at 5.53. In the "Understanding" domain, male and female students performed almost equally, with male students scoring 5.03 and female students scoring 5.04. In the "Application" domain, male students scored 4.64, slightly higher than female students, who scored 4.56. Finally, in the "Higher Level" domain, male students achieved an average score of 4.13, while female students scored marginally lower at 4.08. This comparison showed that male students generally scored slightly higher in most cognitive domains, except for the "Understanding" domain, where female students marginally outperformed male students.

Similarly, the graph 15 below depicted the mean scores of achievements among Male and Female students in a pretest across four cognitive levels.

Figure 15

Plot of mean scores of achievements of Boys and Girls Students Pretest



The descriptive statistics and graph demonstrated small differences in mean achievement scores between male and female students across the cognitive domains. Male students consistently performed slightly better in the Knowledge and Application domains, while female students had a marginal advantage in the Understanding domain. Both genders performed nearly equally in the Higher Level domain. These findings suggest that while differences in performance exist, they are minimal and domain-specific.

The analysis of variance (ANOVA) between males and females were measured in the Table 28. This Table shows that there was effect of gender in the construction of knowledge in the four level of cognitive domain as given in the Table 30.

Table 30

Analysis of Variance (ANOVA) between males and females in Pretest

		Sum of Squares	df	Mean Square	F	Sig.
Pretest of Knowledge	Between Groups	.968	1	.968	.570	.451**
	Within Groups	276.826	163	1.698		
	Total	277.794	164			
Pretest of Understanding	Between Groups	.005	1	.005	.004	.950**
	Within Groups	199.777	163	1.226		
	Total	199.782	164			
Pretest of Application	Between Groups	.258	1	.258	.144	.704**
	Within Groups	291.536	163	1.789		
	Total	291.794	164			
Pretest of Higher level	Between Groups	.111	1	.111	.077	.781**
	Within Groups	233.138	163	1.430		
	Total	233.248	164			

Note. * Significant, ** Not significant at 0.05 level of Significant

Table 30 presented an Analysis of Variance (ANOVA) between male and female students in the pretest across different cognitive levels. The results revealed no statistically significant differences between males and females in pretest scores across all cognitive domains, indicating that both groups entered the study with comparable knowledge and skills. Specifically, the Pretest of Knowledge yielded an F-value of 0.570 and a p-value of 0.451, suggesting equal performance levels. The Pretest of Understanding showed an F-value of 0.004 with a p-value of 0.950, reaffirming the absence of significant differences. Similarly, in the Pretest of Application, the F-value was 0.144 with a p-value of 0.704, while the Pretest of Higher Level recorded an F-value of 0.077 with a p-value of 0.781.

These findings underscored that both male and female students had similar baseline abilities prior to the implementation of the concept mapping method. Consequently, any later differences in performance could be more accurately attributed to the instructional approach rather than pre-existing disparities in cognitive levels. This analysis highlighted the effectiveness of using the concept mapping method as an equitable teaching strategy, enabling a fair comparison of learning outcomes across genders.

Table 31

Comparison between males and females in Pretest across different cognitive levels

Cognitive Levels		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Knowledge	Equal variances assumed	.274	.602	.755	163	.451**
	Equal variances not assumed			.761	145.874	.448**
Understanding	Equal variances assumed	4.298	.040	-.062	163	.950**
	Equal variances not assumed			-.066	160.387	.948**
Application	Equal variances assumed	1.754	.187	.380	163	.704**

	Equal variances not assumed			.372	131.623	.710**
Higher level	Equal variances assumed	.345	.558	.278	163	.781**
	Equal variances not assumed			.281	147.343	.779**

Note. * Significant, ** Not significant at 0.05 level of significant.

Table 31 provided a comparison between males and females in the pretest across different cognitive levels, employing Levene's Test for Equality of Variances and t-tests for Equality of Means. The analysis revealed no statistically significant differences between genders in any cognitive domains assessed. In the Knowledge level, equal variances were confirmed (F = 0.274, p = 0.602), with the t-test showing no significant difference in mean scores (t = 0.755, df = 163, p = 0.451). Similarly, in the Understanding level, although Levene's test indicated a significant result for equal variances (F = 4.298, p = 0.040), the t-test results indicated no significant difference in means (t = -0.062, df = 163, p = 0.950). For the Application level, the analysis also revealed no significant differences (F = 1.754, p = 0.187; t = 0.380, df = 163, p = 0.704), and in the Higher Level, the results indicated no significant differences as well (F = 0.345, p = 0.558; t = 0.278, df = 163, p = 0.781). Thus, these findings suggested that male and female students had comparable cognitive abilities before the intervention, reinforcing the appropriateness of the concept mapping method as a fair instructional strategy, as any future performance differences could be attributed to the intervention rather than pre-existing cognitive disparities between genders.

Table 32

Descriptive Statistics of Males and Females Students in Posttest

Level of Cognitive Domain	Gender of Students	N	Mean	Std. Deviation
Knowledge	Male	67	6.67	1.353
	Female	98	6.19	1.497
Understanding	Male	67	6.06	1.466
	Female	98	5.76	1.332
Application	Male	67	5.51	1.330
	Female	98	5.01	1.328
Higher level	Male	67	5.10	1.361
	Female	98	4.69	1.271

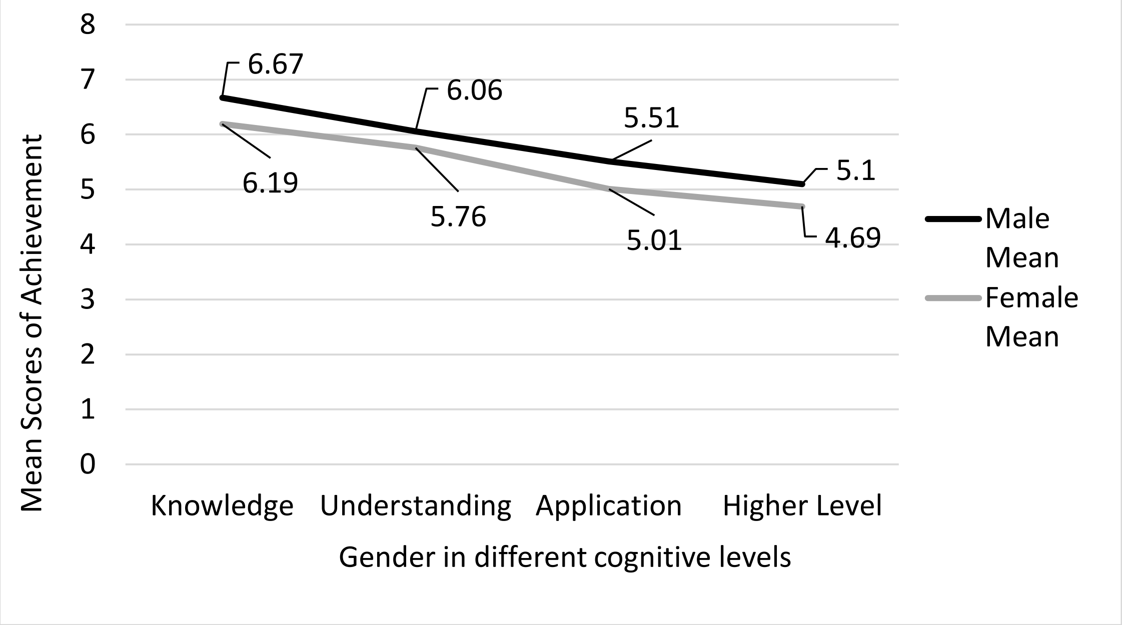
Table 32 presented the descriptive statistics of posttest scores in different cognitive domains for male and female students. In the Knowledge level, male students (N=67) achieved a mean score of 6.67, while female students (N=98) scored 6.19, with standard deviations of 1.353 and 1.497, respectively. For the Understanding level, male students (N=67) scored 6.06, and female students (N=98) scored slightly lower at 5.76, with standard deviations of 1.466 and 1.332, respectively. In the Application level, male students (N=67) obtained a mean score of 5.51, and female students (N=98) scored 5.01, with both groups having standard deviations of 1.330 and 1.328, respectively. Lastly, in the Higher level, male students (N=67) achieved a mean score of 5.10, while female students (N=98) scored 4.69, with standard deviations of 1.361 and 1.271, respectively.

The posttest results indicated that male and female students performed similarly at lower cognitive levels, such as Knowledge and Understanding. Differences emerged primarily in higher cognitive levels, specifically in Application and higher levels, where male students showed a slight performance advantage.

The graph 16 below depicted the mean scores of male and female students across different cognitive levels.

Figure 16

Plot of mean scores of achievements of Male and Female in Post-test



The change in level of cognitive domain that was occurs in posttest was significant and tested by the following Table 33.

Table 33

Analysis of Variance (ANOVA) between males and females in Posttest

Level of Cognitive Domain		Sum of Squares	df	Mean Square	F	Sig.
Knowledge	Between Groups	9.083	1	9.083	4.379	.038*
	Within Groups	338.092	163	2.074		
	Total	347.176	164			
Understanding	Between Groups	3.692	1	3.692	1.917	.168**
	Within Groups	313.884	163	1.926		
	Total	317.576	164			

Application	Between Groups	9.840	1	9.840	5.574	.019**
	Within Groups	287.736	163	1.765		
	Total	297.576	164			
Higher level	Between Groups	6.709	1	6.709	3.918	.049*
	Within Groups	279.085	163	1.712		
	Total	285.794	164			

Note. * Significant, ** Not significant at 0.05 level of Significant

Table 33 presented the results of an Analysis of Variance (ANOVA) that compared male and female students in the posttest across various cognitive levels. The findings revealed significant differences between genders in specific areas while indicating no significant differences in others. In the Knowledge level, the ANOVA results showed a significant difference between males and females (F = 4.379, p = 0.038), suggesting that male students had higher posttest scores compared to female students, indicating a noteworthy performance disparity. Similarly, in the Application level, the analysis indicated a significant difference (F = 5.574, p = 0.019), suggesting that males outperformed females in applying their knowledge. The Higher Level also approached significance (F = 3.918, p = 0.049), further indicating that male students scored higher than female students in higher-order thinking tasks. Conversely, in the Understanding level**,** there were no significant differences between males and females (F = 1.917, p = 0.168), suggesting that both genders had similar capabilities in understanding the material presented in the posttest. The results highlighted that while males outperformed females in the Knowledge, Application, and Higher Level domains, both genders displayed comparable levels of understanding.

Table 34

Comparison between males and females in Posttest across different cognitive levels

Cognitive Levels		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Knowledge	Equal variances assumed	.078	.780	2.093	163	.038*
	Equal variances not assumed			2.133	150.827	.035*
Understanding	Equal variances assumed	.633	.427	1.385	163	.168**
	Equal variances not assumed			1.360	132.787	.176**
Application	Equal variances assumed	.145	.704	2.361	163	.019*
	Equal variances not assumed			2.360	141.788	.020*
Higher level	Equal variances assumed	.160	.690	1.979	163	.049*
	Equal variances not assumed			1.954	135.443	.053*

Note. * Significant, ** Not significant at 0.05 level of significant.

Table 34 presented a comparative analysis of posttest scores between male and female students across different cognitive levels. In the Knowledge level, Levene's Test indicated equal variances (F = 0.078, p = 0.780), allowing for the assumption of equal variances in subsequent analyses. The t-test results revealed a significant difference in means between the genders (t = 2.093, p = 0.038), suggesting that male students performed better than female students in knowledge acquisition. In the Understanding level, while Levene's Test indicated equal variances (F = 0.633, p = 0.427), the t-test results showed no significant difference (t = 1.385, p = 0.168), indicating comparable understanding levels among both genders. In the Application level, equal variances were assumed based on Levene's Test (F = 0.145, p = 0.704), and the t-test revealed a significant difference (t = 2.361, p = 0.019), highlighting that male students outperformed female counterparts in applying their knowledge. Lastly, in the Higher Level, Levene's Test indicated equal variances (F = 0.160, p = 0.690), and the t-test approached significance (t = 1.979, p = 0.049), suggesting a potential difference in higher-order thinking skills between genders, although it did not reach the conventional threshold of significance. The analysis indicated that while males significantly outperformed females in Knowledge and Application, results in the Understanding level showed no significant differences, while the Higher Level domain suggested further exploration of gender differences in cognitive performance, especially in light of instructional interventions like concept mapping aimed at enhancing student achievement.

Conclusion: *The statistical analysis regarding gender revealed no significant differences in pre-test scores between male and female students across all campuses, as well as within the control and experimental groups. However, post-test results indicated that male students outperformed female students across all cognitive domains. In conclusion, while both genders started with similar pre-test scores, the post-test results demonstrated that male students achieved higher scores after being taught using the concept mapping method. This suggests that the concept mapping* *approach was effective for both genders, although the outcomes in achievement varied slightly favoring male students.*

Section 2. Analysis and Interpretation of Qualitative Data

This section deals with the different exploration of effective learning strategies, opportunities perceived and challenges encountered by subject teachers as well as students during the effective use of concept mapping in B.Ed. level physics. They were discussed with reference to the information obtained from the interview conducted by the researcher with respondents in different contexts. The researcher used semi-structured interviews with the subject teachers, as well as students (High, Average, and Low achievers) of the sampled campuses. In this context, it was found that there were effective learning strategies, opportunities and challenges related to the different areas of teaching and learning activities in physics education. The qualitative data were analyzed and interpreted with six steps of the qualitative data analysis method as suggested by (Braun & Clarke, 2006) such as: 1) familiarizing with data 2) generating initial codes 3) searching for themes 4) reviewing themes 5) defining and naming themes 6) and producing the report. For the analysis and interpretation of qualitative data, researchers interviewed students, and cooperating teachers of sampled campuses. Moreover, the researcher has collected the different information about classroom activities that were found in the time of teaching. Since the researcher himself was engaged in each of the classroom activities related to teaching and learning physics, supported the preparation of self-reflection reports.

For the analysis of qualitative data, the researcher has uploaded the interview transcription, self-reflection report of the researcher in qualitative data analysis software ATLAS.ti 9. Each of the interview transcriptions and self-reflection reports was coded and grouped with necessary comments in ATLAS.ti 9. The researcher has prepared different themes, and subthemes categorized the themes and prepared the global theme based on the research questions and objectives.

Exploring effective learning strategies used by students in the concept mapping method

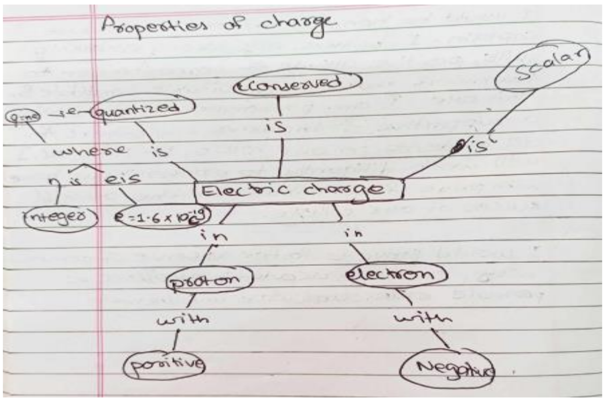
The third objective of this research explored effective learning strategies in the concept mapping method. Interviews with students and teachers highlighted key themes like critical thinking, creativity, collaboration, and active learning during exam preparation. Concept mapping empowered students to engage in critical and creative thinking, create personalized visual representations, and fostered feelings of motivation and accomplishment in their learning journey.

In context of learning strategies an average achiever from the experimental group, described how concept mapping made complex topics more approachable:

> *the topic of Faraday's Ice Pail Experiment, which was taught by our teacher, introduced concept mapping to help us visualize the relationships between different concepts. I remember feeling really happy and excited because I could see how everything connected, and it made the topic so much more approachable. The best part was that we could create our own concept maps, which allowed for a personalized learning experience* (30:17 ¶ 9 in Interview with student from experimental group, 2024).

This excerpt highlighted how concept mapping made complex topics, like Faraday's Ice Pail Experiment, more approachable for an average achiever. The student's positive response reflected the effectiveness of the teacher's use of concept mapping to enhance understanding and emotional engagement. It improved understanding and emotional engagement, allowing students to personalize their learning. This supported the effectiveness of concept mapping in enhancing both comprehension and interest, aligning with constructivist principles. For the exploration of learning strategies, a high-achieving student from experimental group noted the positive impact of concept mapping on their classroom environment.

He remarked that- *concept mapping had significantly contributed to creating a positive and engaging classroom environment. It allowed us to share our understanding and knowledge with peers, fostering a spirit of healthy competition and mutual learning. Presenting our concept maps to the class encouraged us to communicate our thought processes and defend our ideas, promoting critical thinking and analysis* (31:40 ¶ 19 in Interview with student from experimental group, 2024).



From the high achieving student's view in the experimental group, concept mapping fostered an engaging classroom environment. It encouraged creativity and uniqueness by allowing students to share their ideas, leading to healthy competition. This finding, corroborated by previous research by Chandrupatla (2020). Presenting concept maps helped them defend their thought processes, enhancing critical thinking and analytical skills. The similar views were also expressed by a low achiever student of experimental group as:

Using concept mapping in Physics was incredibly advantageous for my learning journey. When I studied the principles of charging by induction, it fostered a deeper level of understanding because I had to think critically about how concepts related to each other. Concept mapping made it easier and *faster for the things and topics to be understood. This method made the students active while learning and also made the teaching and learning environment fun* (19:58 ¶ 15 in Interview with student from experimental group, 2024).

From the above view of a low-achieving student in the experimental group, learning physics was enhanced through concept mapping. This strategy fostered critical thinking and helped visualize relationships, making the subject more engaging. The findings supported prior research by Jena (2019), which indicated that concept map activities improved mastery and recall, highlighting the effectiveness of this active learning strategy in the classroom. In similar theme, another an average achiever student from experimental group expressed that- *In our classes, we began using concept mapping by first selecting a main topic, such as electrostatics. We then identified sub-topics like electric fields, charge distribution, and Coulomb's law. By connecting these concepts with branches, we were able to map out the relationships and structure of the topic clearly, enhancing our understanding of how different elements of electrostatics and electricity interconnect* (32:5 ¶ 5 in Interview with student from experimental group, 2024).

The average achiever student from the experimental group noted that in their classes, they began using concept mapping by selecting a main topic, such as electrostatics, and identifying related sub-topics. By connecting these concepts with branches, they were able to clearly map out the relationships and structure of the topic. This approach enhanced their understanding of how different elements of electrostatics and electricity interconnect, demonstrating the effectiveness of concept mapping as a learning strategy. Regarding classroom strategies, the subject teachers in the experimental group implemented various practices in physics instruction. One of the teachers shared his perspective:

> *What motivated me to use the concept mapping method in my physics teaching was witnessing the positive impact it had on my students' learning experience, particularly when they struggled with topics like lenses and mirrors. This strategy, which involves representing different units and subunits in a flowchart format, allows students to have a clear understanding of the themes of the topics. By differentiating the difficulty levels of content and providing a structured way to study, concept mapping has proven effective in helping students grasp complex concepts and prepare for exams* (5:7 ¶ 13 in Interview with teacher from experimental group, 2024).

The subject teacher from the experimental group noted that the motivation to use concept mapping in physics stemmed from its positive impact on students' learning, especially with challenging topics like lenses and mirrors. This strategy provided a clear flowchart representation of concepts, enhancing understanding. By differentiating content difficulty and offering structured study methods, concept mapping effectively helped students grasp complex ideas and prepare for exams. Likewise, in similar theme another subject teacher of experimental group highlighted his view as:

> *During a concept mapping activity on the topic of electrostatic, I noticed some students expressing joy and elation as they personalized their concept maps. When the students discovered various concepts within this field, they were happy and excited to finally learn the distinctions between electric charge, field, and potential, which freed them from confusion regarding these topics.*

Really, it was satisfying to witness the 'aha' moments. (6:23 ¶ 27 in Interview with student from experimental group, 2024).

The subject teacher from the experimental group highlighted that during a concept mapping activity on the topic of electrostatics, he observed students expressing joy and elation as they personalized their maps. The students felt excitement upon discovering the various concepts within electrostatics, such as electric charge, field, and potential, which helped clarify their understanding of the topic. Witnessing these "aha" moments was particularly satisfying, showcasing the effectiveness of concept mapping as a classroom strategy in enhancing understanding and engagement. These findings were supported by Kpiranyam et al. (2024), who found that peer-collaborative concept mapping effectively enhances students' emotional intelligence and critical thinking in science.

Regarding teaching and learning strategies, one average achiever student from the control group provided his view as:

I can solve voltage divider problems, but I get confused when the teacher asks us to predict how changing the resistors will affect the voltage. I feel like I'm just following steps without understanding. We practice a lot by writing down the formulas and solving similar problems, but it doesn't help me understand how the circuit actually works (27:19 ¶ 11 in Interview with student from control group, 2024).

The average achiever student in the control group revealed a significant issue with the teacher's conventional teaching method, which focused on rote memorization and procedural practice. While the student could solve voltage divider problems, he felt confused about how changing resistors affected voltage, indicating a lack of deep understanding. This highlighted the need for more effective instructional methods, such as conceptual teaching, that promote engagement and understanding of the material in the physics curriculum.

In the exploration of classroom strategies, a subject teacher from the control group focused that- *In my lessons about transformers, particularly in the context of hydropower generation. I emphasize how transformers step up the voltage for efficient energy transmission over long distances. I have students take detailed notes on their functions and the physics behind them. While this helps them memorize key terms, I often observe that they struggle with problem-solving when faced with complex scenarios, such as calculating energy losses or understanding the transformer's role in the overall system* (1:16 ¶ 29 in Interview with teacher from control group, 2024).

The subject teacher in the control group indicated that his lessons on transformers, particularly regarding hydropower generation, emphasized the memorization of functions and physics concepts. While this approach helped students retain key terms, he observed that they struggled with problem-solving in complex scenarios, such as calculating energy losses or understanding the transformer's role in the overall system. This highlighted a gap in the effectiveness of the teaching strategy, suggesting a need for more integrated problem-solving methods.

Conclusion: *Students learned effectively through the concept mapping method by engaging in a process that emphasized originality, creativity, and personalized learning. The visual organization of concepts fostered deeper understanding and critical thinking, allowing students to take ownership of their learning and making challenging subjects more approachable. The collaborative nature of concept mapping enhanced peer interactions, leading to heightened motivation and a sense of accomplishment.*

In contrast, students in the control group, who relied on conventional teaching methods, faced challenges such as over-reliance on rote memorization and difficulty connecting concepts. Teachers in this group also observed that these methods limited students' critical thinking and problem-solving skills, leading to disengagement. The findings underscored the effectiveness of concept mapping as an instructional strategy that not only enhances comprehension but also enriches the overall educational experience.

Opportunities with Concept Mapping by Teachers and Students

The fourth objective of this research was to identify the opportunities perceived by teachers and students for the effective use of concept mapping in teaching and learning activities. Several themes emerged in exploring the opportunities facilitated by the concept mapping method in teaching and learning, as revealed through interviews with teachers and students. These encompassed Expanding pedagogical horizons**,** teaching insights with concept mapping**,** Empowering ownership and curiosity, Creating an Engaging Classroom Environment. Reflecting on these insights, both teachers and students from the experimental group shared their perspectives on the opportunities associated with concept mapping, providing valuable glimpses into the multifaceted benefits observed in the context of their learning journey.

Teachers from experimental group contributed to the conversation within this theme, offering valuable perspectives on the opportunities presented by integrating concept mapping into physics education in the following manner:

> The first teacher from experimental group told that – *Yes, I definitely plan to use concept mapping in other courses and endeavors. I have witnessed the positive impact of concept mapping on my students' understanding and*

> *engagement in physics. The versatility of concept mapping makes it applicable to various subjects, allowing students to connect concepts in a visual and meaningful way* (5:23 ¶ 31 in Interview with teacher from experimental group, 2024).

The teacher from the experimental group expressed enthusiasm for applying concept mapping in other subjects, emphasizing its positive impact on students' understanding and engagement in physics. This reflection underscored the versatility of concept mapping, demonstrating that it not only deepened comprehension in physics but also held potential for broader application across various disciplines. By expanding pedagogical horizons, this perspective illustrated that concept mapping provided teachers with an adaptable strategy to promote interconnected thinking and deeper learning in different subject areas. Likewise, the second subject teacher from the same group emphasized the opportunities that concept mapping offers as a teaching tool. He focused that –

> *student engagement, active learning, and curiosity are critical non-cognitive factors that contribute to a happy learning environment in physics education. Incorporating concept mapping, group discussions, and problem-solving tasks, I aim to keep students engaged and enthusiastic about physics. By valuing their contributions and encouraging intellectual curiosity, a joyful learning environment where students are eager to explore and inquire about the subject is formed* (7:16 ¶ 29 in Interview with teacher from experimental group, 2024). Finally, he concluded that - *in my teaching practice, the concept mapping method has proven to be a valuable tool for imparting knowledge in an easy and efficient manner* (7:20 ¶ 33 in Interview with teacher from experimental group, 2024).

The second subject teacher from the experimental group emphasized the significant opportunities that concept mapping provided as a teaching tool. By incorporating strategies that promoted student engagement, active learning, and curiosity, the method contributed to a more positive and stimulating learning environment in physics. This approach, which combined group discussions and problem-solving tasks, effectively kept students motivated and eager to explore the subject. The teacher's reflection demonstrated that concept mapping not only simplified complex topics but also created an atmosphere of intellectual curiosity and active participation, reinforcing its value as an instructional strategy. Additionally, in a related context of opportunities identified through concept mapping, the third subject teacher from the experimental group highlighted:

> *The concept mapping method played a vital role in influencing their attitudes by fostering a sense of ownership over their learning and promoting a deeper understanding. As their curiosity grew, they became more proactive in seeking additional resources and engaging in discussions, leading to a positive shift in their motivation and investment in the subject* (7:18 ¶ 31 in Interview with teacher from experimental group, 2024).

The third subject teacher emphasized that concept mapping created opportunities by fostering student ownership of learning, enhancing curiosity, and promoting deeper understanding. These opportunities led to increased motivation and active participation, transforming classroom dynamics and engagement in physics education. Moreover, another subject teacher from the same group, in a similar context of opportunities recognized through concept mapping, emphasized:

> *Indeed, I have observed notable changes in my students' attitudes and motivation toward physics since incorporating concept mapping. The method*

> *has sparked intrinsic curiosity and a desire to explore the subject further. Ever since there has been the use of this idea, the classes are becoming more effective. Student participation and engagement in Q&A's and discussions are much more frequent than in the silent classes before, which certainly is an improvement* (7:17 ¶ 31 in Interview with teacher from experimental group, 2024).

Again, the subject teacher from the experimental group observed that concept mapping led to increased student motivation and curiosity in physics. The method made classes more interactive, with greater student participation in discussions and Q&A sessions. This shift from passive to active engagement highlighted the effectiveness of concept mapping in fostering a more dynamic and participatory learning environment. The teacher's insight reinforced the idea that concept mapping enhanced both student interest and classroom effectiveness, offering valuable opportunities for more meaningful learning experiences. These results echoed Jena (2019), demonstrating improvements in students' understanding and retention while highlighting the benefits of this active learning approach in fostering an interactive classroom. Regarding the opportunities presented by concept mapping, an average student from the experimental group shared his thoughts:

> *Yes, I used concept mapping to explain the concept of electrical circuits like Ohm's law to my peers during a group study session. Initially hesitant, my friends encouraged me to attempt it. Making a concept map compelled us to consider the essential elements and relationships in topic Ohm's law. It felt fantastic to see them engaged and asking questions as I navigated through the concept map* (20:43 ¶ 22 in Interview with student from experimental group, 2024).

According to the perspective above, the average student in the experimental group was aware of the opportunity concept mapping provided to enhance comprehension of electrical circuits, particularly Ohm's law. Initially hesitant, encouragement from peers led the student to create a concept map, prompting careful consideration of key elements and their relationships. This engagement fostered deeper learning and stimulated active participation and inquiry among classmates, highlighting how concept mapping can enhance collaborative learning and build confidence in explaining complex concepts. In a similar vein, a high-achieving student from the experimental group reflected on the opportunities provided by concept mapping:

> *Presenting our concept maps to the class encouraged us to communicate our thought processes and defend our ideas, promoting critical thinking and analysis. For example, when mapping out the concepts of electric field intensity, we had to clearly explain and justify the connections between electrostatic force, electric lines of force, and flux. This interactive approach to learning Physics not only deepened our understanding of complex theories but also made the classroom environment vibrant and intellectually stimulating* (31:41 ¶ 19 in Interview with student from experimental group, 2024).

From the insights shared by a high-achieving student in the experimental group, it was clear that presenting concept maps facilitated communication and defense of ideas, enhancing critical thinking. While mapping electric field intensity, students had to explain and justify the connections among electrostatic force, electric lines of force, and flux. This interactive learning approach deepened their understanding of complex theories and fostered a dynamic classroom environment.

Ab Latif (2018) also supported these findings by revealing that students recognized the benefits of using concept mapping as a teaching tool. Furthermore, concerning the opportunities recognized in the context of teaching physics, a subject teacher from the control group shared his insights:

> *I noted that my reliance on continuous lectures when teaching series and parallel circuits for determining equivalent resistance limited opportunities of students for collaboration and engagement in classroom. Students often memorized how to calculate equivalent resistance but missed out on deeper understanding through interactive discussions* (1:34 ¶ 42 in Interview with teacher from control group, 2024).

The subject teacher from the control group recognized that his reliance on continuous lectures in teaching series and parallel circuits restricted opportunities for student collaboration and engagement. While students could memorize calculations for equivalent resistance, they lacked the chance to engage in interactive discussions that promote deeper understanding, highlighting the missed potential for fostering a more dynamic learning environment where students could explore concepts collaboratively and develop critical thinking skills. In a similar context, a low-achieving student from the control group shared his perspectives on the opportunities observed in physics teaching:

> *When teacher explained about combination of batteries in circuits, I could remember the rules about how they worked. However, I found it difficult to understand how those rules applied to real-life situations. This made it hard for me to engage with the topic fully because I didn't see the connection between what I was learning in class and how batteries function in everyday life* (26:9 ¶ 8 in Interview with student from control group, 2024).

Insights from a low-achieving student in the control group revealed that the teaching approach lacked real-life relevance. Although the student could recall rules about battery combinations in circuits, the inability to connect these rules to practical applications hindered engagement and comprehension. This gap underscored the missed opportunity to foster deeper understanding and interest in physics, emphasizing the need for instructional strategies that link classroom learning to real-world contexts.

Conclusion: *In conclusion, the analysis of the opportunities perceived through concept mapping by both teachers and students underscores its effectiveness as an educational strategy that fosters meaningful learning and active engagement. Teachers recognized that concept mapping expanded their pedagogical horizons, promoted student ownership, and created a more stimulating learning environment. Similarly, students reported increased confidence, collaboration, and critical thinking skills as a result of using concept maps in their studies. In contrast, responses from the control group indicated a lack of engagement and real-world relevance in traditional teaching methods, highlighting the missed opportunities for deeper understanding. The integration of concept mapping within the educational framework not only aligns with Ausubel's and constructivist principles but also embodies the pragmatic philosophy, paving the way for enriched learning experiences in physics education.*

Challenges Encountered by Teachers and Students in Concept Mapping

The fifth objective of this research was to identify the challenges teachers and students encountered while using the concept mapping method in physics education. Interviews with teachers and students in the experimental group revealed several themes, including perceived difficulty and complexity in creation, coping with concept mapping, linguistic hurdles, and demonstrating pedagogical prowess. These insights highlighted the various obstacles students faced in their physics education when employing concept mapping.

Teachers from the experimental group participated in the discussion of this theme, providing valuable insights into the challenges associated with integrating concept mapping into physics education, such as:

The first teacher from the experimental group stated that - *Well, for short, relations and terms concept maps are quite easy to represent, but the problems are seen when there is a need to derive a complex relation or derivation. It is useful in topics where connections and links are present* (2:11 ¶ 19 in Interview with teacher from experimental group, 2024).

The first teacher from the experimental group recognized that representing straightforward relationships and terms using concept maps was relatively easy; however, difficulties emerged when attempting to illustrate complex relations or derivations. This finding aligned with a previous study conducted by Machado and Carvalho (2020) on constructing effective concept maps. This observation emphasized the method's strength in facilitating understanding in topics with clear connections while also revealing its limitations in addressing intricate concepts. Such insights indicate that, while concept mapping is a valuable tool for enhancing comprehension, additional strategies may be necessary to effectively convey more complex material. Similarly, the second subject teacher from the same group expressed views similar to the first teacher regarding the challenges associated with using concept mapping, stating that:

Sometimes, I found it challenging to incorporate concept mapping while making circuit diagrams and differential equations where both diagrams and concept

> *maps were necessary to explain. activities without adding extra time to the curriculum. Balancing concept mapping and ensuring that it complemented the overall learning experience required strategic thinking and creativity* (6:25 ¶ 29 in Interview with teacher from experimental group, 2024).

The second teacher from the experimental group echoed the sentiments of the first regarding the challenges of integrating concept mapping into lessons. This teacher found it particularly difficult to combine concept mapping with circuit diagrams and differential equations, noting that both tools were essential for effective explanation. The necessity of incorporating concept mapping without extending the curriculum highlighted the need for strategic planning and creativity to ensure that this method enhanced rather than disrupted the learning process. In addition, within the context of challenges associated with concept mapping, the third subject teacher from the experimental group pointed out:

> *Concept mapping is a helpful tool for teaching and learning, but our curriculum is very packed. For instance, when we cover complex topics like Kirchhoff's law, its derivations and numerical problems, we have to rush through everything. This rush makes it hard to use tools like concept maps in our lessons. Even though concept mapping could help students understand ideas like voltage, current, and resistance better, the pressure to finish the syllabus on time makes it challenging to include it in our teaching* (7:14 ¶ 27 in Interview with teacher from experimental group, 2024).

The third subject teacher from the experimental group recognized the value of concept mapping but noted challenges posed by a packed curriculum. The need to rapidly cover complex topics like Kirchhoff's law and its derivations made it difficult to incorporate concept maps effectively. Although concept mapping could improve students' grasp of concepts such as voltage, current, and resistance, time constraints limited its use, highlighting the disconnect between the tool's benefits and the pressures of curriculum requirements. Concerning the challenges associated with concept mapping, an average achiever student from the experimental group expressed his views:

> *For instance, if we are making a concept map about electric field intensity, we needed to know what exactly the topic was about. So, if we didn't know about concepts, then how could we put them together in the construction of the map* (18:46 ¶ 27 in Interview with student from experimental group, 2024). He further added that - *Concept mapping in Physics was generally helpful, but I did encounter a challenge when trying to incorporate some complex formulas and mathematical relationships into the maps* (18:47 ¶ 29 in Interview with student from experimental group, 2024).

An average-achieving student from the experimental group highlighted significant challenges in using concept mapping for physics. He emphasized the necessity of understanding the topic thoroughly, noting that a lack of foundational knowledge hindered his ability to construct effective concept maps. Additionally, he acknowledged the usefulness of concept mapping but faced difficulties when trying to integrate complex formulas and mathematical relationships, indicating that the intricacies of physics concepts posed barriers to effectively utilizing this tool. This finding was consistent with the study by Machado and Carvalho (2020), which explored the development of effective concept maps. In addition, regarding the challenges related to concept mapping, a low-achieving student from the experimental group shared his perspective:

> *To address the challenges appeared in physics concepts, I started by creating a rough outline of the map and gradually added the details. I also used different colors and shapes to visually distinguish the different levels of hierarchy. This approach helped me overcome the challenge and create concept maps that better conveyed the relationships between the Physics concepts* (24:63 ¶ 29 in Interview with student from experimental group, 2024).

From the above view, a low-achieving student in the experimental group exemplified effective coping with the concept mapping tool. By starting with rough outlines and progressively adding details, the student organized complex physics concepts more clearly. The strategic use of colors and shapes to represent different levels of hierarchy further facilitated understanding, showcasing how visual differentiation can enhance the effectiveness of concept mapping in learning. This experience aligns with Eshuis et al. (2022), which emphasized that supporting students in the cognitive processes of concept mapping is crucial for effective learning. Similarly, a second average achieving student from the experimental group shared his reflections on the challenges associated with concept mapping:

> *I thought the language barrier was a great problem for using and understanding this new teaching method. Many students were usually familiar with Nepali medium of learning so all of a sudden, switching to concepts written in English made it difficult to comprehend the whole idea. We were unable to make out the pattern in which the concept map was flowing in* (20:60 ¶ 28 in Interview with student from experimental group, 2024).

A second average-achieving student in the experimental group noted that language barriers posed significant challenges when using concept mapping. The sudden shift from learning in Nepali to engaging with English-written concepts made it difficult for students to grasp the structure and flow of the concept maps. Likewise, a high achiever student from control group echoed that:

> *I came here from a Nepali background, and learning in English made it hard to express my thoughts during class discussions. I often struggled with technical terms, which hindered my engagement. Since the teacher only writes notes on the whiteboard, it's challenging to follow along. I hesitated to participate because I worried about using the wrong terms or grammar, impacting my confidence* (28:54 ¶ 27 in Interview with student from experimental group, 2024).

A high-achieving student from the control group expressed similar difficulties as average student in experimental group in engaging during class discussions due to the language barrier, having come from a Nepali background and learning in English. The student noted that the challenge of expressing thoughts and understanding technical terms hindered active participation. Additionally, reliance on traditional note-taking methods by the teacher, such as writing on the whiteboard, made following the lessons more difficult. These perspectives related to language barriers of both experimental and control group students were supported by Chiang (2021) findings, which emphasized the crucial role of language in education and the importance of incorporating effective language strategies to enhance learning outcomes. This apprehension about making language-related mistakes further diminished the student's confidence, affecting overall engagement in the learning process. Furthermore, again same high achieving student from the control group offered his views on the challenges encountered in physics instruction:

> *I usually understand the lessons well, but I sometimes get confused when applying multiple concepts together in complex problems that were not covered in class. We don’t have enough class time to solve more complex problems, and the teacher also doesn’t connect these problems with real-life experiences* (28:59 ¶ 29 in Interview with student from control group, 2024).

Same high-achieving student from the control group also identified challenges in physics instruction, noting that while he generally understood the lessons, he often felt confused when applying multiple concepts to complex problems not covered in class. The limited class time for solving more complex problems compounded this confusion, along with the teacher's failure to connect these problems to real-life experiences. This lack of connection and time highlighted a gap in the instructional approach, suggesting the need for more comprehensive teaching methods that integrate practical applications and address complex problem-solving.

Additionally, with respect to the challenges noted in teaching physics, a subject teacher from the control group provided his insights:

One major challenge is the lack of time to cover the syllabus in depth. We are often rushed to complete the curriculum, which forces me to skim over certain concepts that require more attention. Mathematics integration in physics is also a bit difficult, and solving numerical problems is time-consuming (1:13 ¶ 26 in Interview with teacher from control group, 2024).

From the insights provided by the subject teacher in the control group, critical challenges in teaching physics were identified, primarily the limited time available for in-depth syllabus coverage. This rush led to a superficial treatment of key concepts and hindered students' understanding. Additionally, the teacher noted difficulties in integrating mathematics with physics, emphasizing that solving numerical problems was time-consuming. These challenges highlighted the necessity for more effective instructional strategies to enhance comprehensive learning.

Conclusion: *Both teachers and students in the experimental group faced significant challenges with concept mapping in physics due to complex concepts and inadequate foundational knowledge. Students struggled to create effective maps because of difficulties with numerical problems, higher-order thinking, and formula derivation, highlighting the need for improved teacher training. Students, particularly those with average achievement levels in the experimental group, struggled to construct effective concept maps due to gaps in their foundational knowledge and language barriers. Teachers also found it challenging to integrate concept maps with intricate topics while managing a packed curriculum. Similarly, the control group experienced time constraints, difficulties in integrating mathematics into physics lessons, and also language barrier problems. Both groups underscored the necessity for instructional strategies that connect concepts to real-life applications and foster deeper understanding. Ultimately, the findings suggest that while concept mapping can be valuable, its effectiveness relies on prior knowledge, supportive teaching methods, and a flexible curriculum that accommodates complex learning needs.*

Summary

This chapter provided a detailed analysis and interpretation of the data collected to evaluate the effectiveness of the concept mapping method in physics education. The aim was to explore how this teaching strategy influenced students' achievement and engagement compared to conventional methods. The preliminary attitude test toward physics revealed similar readiness levels among both the control and experimental groups before the intervention; thus, both groups were equally prepared for physics education. Moreover, an Independent Samples Test indicated no statistically significant differences in pre-test scores, yet the post-test results showed that the experimental group achieved significantly higher scores than the control group, highlighting the effectiveness of the concept mapping method. Furthermore, the analysis confirmed that the concept mapping method positively influenced achievements in lower cognitive domains, although challenges persisted in applying knowledge to complex cognitive tasks, suggesting the need for targeted interventions. In addition, statistical analysis showed no significant differences in pre-test scores between male and female students, but post-test results indicated that male students outperformed females, demonstrating that while the concept mapping approach benefitted both genders, outcomes varied slightly.

In addressing the third objective, which aimed to explore effective learning strategies employed by students in the concept mapping method, the research revealed that students actively utilized strategies such as critical thinking, creativity, and collaboration to enhance their understanding. Interviews highlighted how concept mapping encouraged creative connections and personalized learning, fostering deeper comprehension and increased motivation.

For the fourth objective, the research identified key opportunities perceived by teachers and students in using concept mapping. These included expanding pedagogical horizons, gaining new teaching insights, and fostering student ownership and curiosity, contributing to a more engaging classroom environment.

Furthermore, in addressing the fifth objective, the research revealed challenges faced by teachers and students, such as the complexity of creating concept maps, coping with the process, and linguistic barriers. These findings highlighted the need for targeted teacher training to maximize the benefits of concept mapping in education.

CHAPTER V

Findings and Discussion

Introduction

This chapter elucidates the findings and engages in a detailed discussion surrounding the " Concept Mapping Method on Students' Achievement in Science Education at Higher Level." This study, guided by five objectives and seven research questions, examined the effectiveness of concept mapping teaching methods on bachelor-level students' academic achievement in physics within science education. Additionally, the chapter explores the effective learning strategies, opportunities, intricate challenges and impediments faced by both students and educators in integrating the concept mapping strategy within the context of bachelor-level of science education.

A range of methods and strategies, such as active learning, collaborative learning, and personalized learning, were employed in applying the concept mapping method in physics education. Students actively constructed their own concept maps to deepen understanding and foster critical thinking.Scaffolding was used to support students in building their maps, gradually reducing assistance as they gained proficiency. Visual learning was enhanced through concept maps, helping students organize and retain complex information. Specifically, the study examined the different strategies through which students effectively learned using concept mapping, as well as the opportunities and challenges identified by both teachers and students.

The key questions explored in this section included: How do students learn effectively in the concept mapping method? What opportunities do teachers and students perceive when using this method? What challenges do they encounter during its application? Furthermore, how can we resolve these challenges and promote the opportunities presented by concept mapping in the teaching and learning process?

The findings were analyzed in relation to relevant theoretical frameworks and empirical literature, incorporating quantitative data supported by qualitative insights to provide a detailed understanding.

Findings with Discussion of Research

Findings

Upon scrutinizing and interpreting the data, the researcher drew conclusions and identified implications for future studies. The initial section outlined the study's conclusions drawn from research analysis, while the concluding part provided recommendations based on other findings of the study.

Finding of the Study

The score obtained from the achievement test of control and experimental group was analyzed by the SPSS version 20 application. Researcher calculated the mean, standard deviation, variance, variance, correlation and two-tailed significance value. The findings of this research were derived from the different research questions. These research questions were answered with the quantitative data and further authenticated or explained by the qualitative data.

This section presented the findings and discussions addressing the research questions regarding the effectiveness of the concept mapping method in physics education. Each question was addressed systematically, revealing insights that contributed to understanding the teaching strategy's impact on student achievement and engagement.

***Research Question 1**: What is the achievement score of students in physics by teaching concept mapping and conventional method?*

The answer to the first research question was analyzed using descriptive statistics and independent samples tests for both experimental and control groups. Table 15 shows that the pretest mean score for the control group was 19.43 (SD = 2.405), while the experimental group had a mean of 19.26 (SD = 2.679), indicating similar baseline performances. Following the intervention, the control group's posttest mean score slightly increased to 19.90 (SD = 2.329), whereas the experimental group demonstrated a significant improvement with a mean score of 24.14 (SD = 2.849). The independent samples test revealed a highly significant difference in posttest scores between the two groups, with the experimental group scoring approximately 4.237 points higher than the control group ($p < 0.001$) (see Table 20).

The findings from the study aligned with Ausubel's Theory of Meaningful Learning and Constructivism under the philosophy of Pragmatism. Ausubel's theory emphasized that meaningful learning occurred when learners related new information to their existing cognitive structures (Ausubel, 1963). In this study, the use of concept mapping enabled students to visualize relationships between physics concepts, facilitating deeper understanding and retention. This process allowed learners to construct knowledge actively by engaging with the material and making connections among different concepts, thereby enhancing their problem-solving abilities.

Moreover, the constructivist perspective posited that knowledge was constructed through social interactions and experiences (Schreiber & Valle, 2013). By employing the concept mapping method, students engaged in collaborative learning, discussing and negotiating meanings with their peers. This interaction supported individual learning while fostering a sense of community and shared understanding, crucial in a subject like physics with its complex concepts.

The pragmatist philosophy further supported the integration of these theories, emphasizing the practical application of knowledge and learning through experience (Biesta, 2010). By using concept mapping as a teaching strategy, educators provided students with tools that promoted active learning, critical thinking, and problem-solving skills.

These findings were also supported by Meheux (2017b) and Asubiojo (2018), who found that concept mapping outperformed conventional methods in improving physics achievement.

Conclusion: *The analysis confirmed the acceptance of the research hypothesis and concluded that the concept mapping method significantly enhanced students' achievement in physics compared to the conventional method.*

Research Question 2*: Does concept mapping method improve students' achievement in physics across different cognitive levels?*

The second research question concerned the effectiveness of the concept mapping method in enhancing students' achievements across various cognitive domains, specifically knowledge, understanding, application, and higher-level. The findings revealed that the concept mapping intervention significantly influenced students' achievements in lower cognitive domains, with substantial improvements observed in the posttest results.

Table 19 highlighted the posttest performance of the Experimental and Control groups across these cognitive domains. The Experimental group (N=95) demonstrated a notable increase in mean scores compared to the Control group (N=70) in all domains: Knowledge (6.92 vs. 5.67), Understanding (6.37 vs. 5.21), Application (5.52

vs. 4.80), and Higher Level (5.34 vs. 4.21). The standard deviations remained relatively consistent, indicating stable performance within each group.

The analysis of variance (ANOVA) presented in Table 21 confirmed significant differences between the Experimental and Control groups in all cognitive domains, with p-values indicating strong statistical significance ($p < 0.001$ for Knowledge, Understanding, and Higher Level; $p = 0.001$ for Application). This statistical evidence substantiated the effectiveness of the concept mapping method as an instructional strategy, reinforcing its role in promoting higher cognitive engagement among students.

Cohen's d calculations further elucidated the practical significance of these findings, revealing large effect sizes for Knowledge (0.95), Understanding (0.92), and Higher Level (0.95), alongside a medium effect size for Application (0.55). These results emphasized that the concept mapping method not only led to statistically significant differences but also had a meaningful impact on students' cognitive achievements (see Table22).

The post hoc analysis, as shown in Table 23, further illustrated the effectiveness of the concept mapping method, with significant mean differences observed among cognitive levels. Students achieved higher scores in Knowledge compared to Understanding, Application, and Higher Level, indicating robust foundational knowledge acquisition. While Understanding scores were also significantly higher than those in Application and Higher Level, the smallest mean difference was between Application and Higher Level, emphasizing challenges in applying knowledge to complex contexts.

Additionally, the correlation analysis in Table 24 revealed significant positive relationships between the posttest scores across cognitive domains, with students demonstrating interconnectedness in their performance. This suggested that proficiency in one cognitive area positively influenced achievement in others, although the strength of these associations varied.

This is consistent with Novak (1983), who demonstrated that concept mapping helps students create meaningful connections between concepts, thereby improving their cognitive understanding. Novak (1983) found that students who used concept maps showed enhanced conceptual understanding and were able to integrate new information with their pre-existing knowledge structures.

The findings related to the second research question aligned with Ausubel's Theory of Meaningful Learning and constructivism within the philosophy of pragmatism. Ausubel's theory highlighted that meaningful learning occurs when learners connect new information to their existing cognitive structures (Ausubel, 2012). The significant improvements in students' achievements across cognitive domains demonstrated that the concept mapping method facilitated this relational learning by visually organizing concepts.

Constructivism emphasized active engagement in knowledge construction (Schreiber & Valle, 2013). The concept mapping method encouraged students to connect and organize ideas, resulting in higher posttest scores and improved application of knowledge. This reflected the active learning process central to constructivism.

Pragmatism focused on the practical application of knowledge (James, 2001). The significant cognitive improvements indicated that the concept mapping method effectively bridged theoretical knowledge and real-world application, fostering higher cognitive engagement. These findings illustrated that the concept mapping method not only enhanced cognitive achievements but also supported active participation and meaningful connections in learning.

Conclusion: *The analysis confirmed the acceptance of the research hypothesis. The findings confirmed that the concept mapping method significantly enhanced students' achievements in lower cognitive domains while also highlighting challenges in transitioning to higher-order thinking skills. These results underscored the need for targeted interventions that not only built on students' strengths but also addressed the difficulties they faced in applying their knowledge to more complex tasks.*

Research Question 3*: Is there any significant difference in achievement between male and female students, at various cognitive levels, when taught using the concept mapping method versus conventional method?*

The answer to the third research question was analyzed using pre-test and post-test scores to investigate gender differences in student achievement when taught using the concept mapping method versus the conventional method. The investigation revealed several important insights.

Pre-test scores across all campuses indicated no statistically significant difference between male and female students. The mean scores for males (19.46) and females (19.24) demonstrated comparable performance, with a p-value of 0.593, confirming that no significant difference in pre-test scores between male and female students (see Table 25). This trend was consistent across both the control and experimental groups, reinforcing the idea that both groups entered the study with similar cognitive abilities.

In the pre-test analysis of cognitive domains, male students generally scored slightly higher than female students in the Knowledge and Application domains, while females had a marginal advantage in the Understanding domain. However, these differences were minimal, suggesting that both genders had similar foundational knowledge and skills before the intervention.

The post-test results painted a different picture. Males significantly outperformed females across the Knowledge, Application, and Higher Level cognitive domains. Specifically, the ANOVA results revealed significant differences in the Knowledge ($F = 4.379$, $p = 0.038$) and Application ($F = 5.574$, $p = 0.019$) levels, indicating that male students scored higher in both areas. The Higher Level domain also showed a trend toward significance ($F = 3.918$, $p = 0.049$), suggesting a performance gap in higher-order thinking tasks. In contrast, no significant differences were found in the Understanding domain ($F = 1.917$, $p = 0.168$), indicating that both genders had similar levels of comprehension of the material (see Table 32).

The comparison using Levene's Test for Equality of Variances and t-tests further confirmed these findings. Significant differences were observed in the Knowledge ($t = 2.093$, $p = 0.038$) and Application ($t = 2.361$, $p = 0.019$) domains, while the Understanding domain revealed no significant differences ($t = 1.385$, $p = 0.168$). The Higher Level domain approached statistical significance ($t = 1.979$, $p = 0.049$) (see Table 33).

These results align with the findings of Cheema and Mirza (2013) and Sakata (2016), who reported significant effects of gender on achievement in favor of the male students. However, they contradict the findings of Sakiyo and Waziri (2015), Ogonnaya et al. (2016), Enebechi and Nzewi (2017), Doris (2018), Ugwumba (2020), and Jena (2021) who found no significant difference between male and female students taught using concept maps. The gender-biased nature of concept maps in the physics classroom posed challenges for teachers in maintaining balanced conceptual understanding and performance between genders. Moreover, the findings of this study contribute to the expanding body of research that supports concept mapping as an effective tool for enhancing student achievement in science education.

The answer to the third research question was analyzed using pre-test and post-test scores to investigate gender differences in student achievement when taught using the concept mapping method versus the conventional method. The findings revealed notable insights aligned with Ausubel's Theory of Meaningful Learning and Constructivism under the philosophy of Pragmatism.

Initially, both male and female students showed no statistically significant differences in pre-test scores, indicating they entered the study with similar cognitive structures. This foundation allowed both genders to have comparable foundational knowledge in the Knowledge and Application domains. However, the post-test results highlighted a significant achievement gap favoring male students in the Knowledge, Application, and Higher Level cognitive levels. This divergence reflected the principles of Constructivism, as the concept mapping method appeared to facilitate better engagement and deeper understanding for male students. The lack of significant differences in the Understanding domain suggested that both genders comprehended the material equally, emphasizing the contextual nature of learning highlighted by Pragmatism.

The analysis indicated that while male and female students started with similar cognitive abilities, the post-test results demonstrated a significant achievement gap favoring males. This finding underscored the effectiveness of the concept mapping method and highlighted the need for strategies that promote equal engagement and support for female students in complex cognitive tasks.

Conclusion*: The analysis validated the research hypothesis as accepted. The analysis indicates that while male and female students started with similar cognitive* *abilities, post-test results demonstrate a notable achievement gap favoring male students in the context of the concept mapping method. This finding highlighted the effectiveness of the concept mapping approach in enhancing student learning outcomes; however, it also revealed performance disparities, particularly for female students in the higher-level domains.*

Now an obvious question arises: Why was the concept mapping intervention not equally effective for both genders in application and higher-level cognitive tasks? If male and female students entered the study with similar cognitive abilities, as indicated by the pre-test results, why did males significantly outperform females in the post-test? What factors contributed to this performance gap, and what strategies are needed to enhance the cognitive abilities of female students? To explore these, a qualitative approach was employed, incorporating interviews with both male and female students, class observations, and reflective diaries. The interviews provided rich insights into individual perspectives and experiences, while class observations allowed for a deeper understanding of the interactive dynamics between students and the teaching method. Reflective diaries offered a personal account of the students' engagement, challenges, and strategies for learning. These sources of information helped uncover underlying factors contributing to the performance gap. By analyzing these data, the study aimed to identify strategies needed to enhance the cognitive abilities of female students and ensure that both genders can apply their knowledge and skills effectively in similar contexts. These question requires further exploration to understand how gender influences the application of concept mapping in developing higher-level cognitive skills.

Research Question 4*: How do students learn effectively in concept mapping method?*

The fourth research question was related to the teaching and learning strategies of teachers and students in both groups (Experimental and Control group) of the study. Based on the findings, students in the experimental group, who used the concept mapping method, demonstrated more effective learning through several strategies that promoted active involvement, critical thinking, and personalized learning experiences. The concept mapping approach empowered students to engage in critical and creative thinking, create personalized visual representations, and foster feelings of motivation and accomplishment in their learning journey. Additionally, it enabled students to visually connect various concepts, making complex topics more understandable and facilitating deeper learning.

Students in the experimental group engaged in critical and creative thinking by organizing information into structured visual maps. For example, during an interview, one student highlighted how concept mapping simplified difficult topics, such as Faraday's Ice Pail Experiment, by allowing them to visualize relationships between different concepts. This process enhanced comprehension and made abstract topics more approachable, showcasing the method's effectiveness in breaking down complex subjects. This finding was supported by Ab Latif (2018), Sharma et al. (2013), and Yazidi (2023) who underscored the crucial role of the chosen concept mapping approach in developing 21st-century competencies, particularly fostering critical thinking among learners.

The concept mapping method also supported personalization of learning, as students created their own maps based on their individual understanding. This autonomy allowed them to build deeper connections between key topics, such as electric fields and Coulomb's law, which contributed to a more meaningful educational experience. The freedom to design personalized maps fostered creativity and increased engagement in subjects like electrostatics. In favor of this finding, previous research conducted by Chandrupatla (2020), Cakiroglu et al. (2022), and Oni et al. (2023) have highlighted the ability to nurture ownership and curiosity, thereby enhancing students' participation with concept mapping.

Moreover, peer collaboration and engagement were vital components of the concept mapping approach. Students shared their maps with classmates, fostering discussions and healthy competition. This interaction promoted mutual learning, critical thinking, and analysis, as students exchanged ideas and defended their reasoning. A high-achieving student noted that this collaborative environment enriched the classroom experience and broadened their understanding of the material through diverse perspectives. This finding aligned with Kinchin et al. (2005), and Sharma et al. (2013), who observed students learning from each other in small groups during concept mapping. This type of learning aspect provides an opportunity to explore how collaborative efforts in constructing concept maps contribute to a deeper insights of science concepts.

Emotional engagement was another significant factor in the success of concept mapping. Several students expressed feelings of excitement and satisfaction when they successfully visualized and understood challenging concepts. Teachers observed that these “aha” moments were particularly pronounced when students made connections between complex topics like electric charge and potential. This emotional involvement enhanced students' motivation and eagerness to continue learning, further reinforcing the method’s benefits.

Active learning was also a key element, as the concept mapping method required students to actively participate in organizing and linking concepts. A low-achieving student mentioned that this interactive approach helped them think critically and accelerated their learning process, making physics more engaging. This active participation not only improved retention of knowledge but also prepared students effectively for exams, as they could recall and apply concepts with greater ease.

In contrast, interviews with students in the control group, who followed conventional teaching methods, encountered difficulties with connecting theoretical knowledge to practical applications. While they could memorize formulas and key terms, they often struggled with problem-solving tasks and understanding how concepts applied in real-world scenarios. Teachers reported that these students lacked the critical thinking and problem-solving skills needed for deeper comprehension, which highlighted the limitations of traditional teaching strategies.

To address the fourth research question of this research, which explored effective learning strategies in the concept mapping method, it is crucial to integrate the theoretical foundations of pragmatism, constructivism, and Ausubel's Meaningful Learning Theory with empirical evidence from the study.

The analysis of interviews underscored the alignment between pragmatism, constructivism, and Ausubel's Meaningful Learning Theory with the empirical evidence from this study. Pragmatism emphasizes the practical value of educational methods, evident as students used concept mapping to connect physics concepts to real-world applications, such as mapping circuits to solve electrical problems, enhancing their understanding and retention (Biesta, 2010; James, 2001). Ausubel's theory suggests that meaningful learning occurs when new information connects to prior knowledge (Ausubel, 1963). Furthermore, constructivism, as articulated by Vygotsky, posits that learners actively build knowledge through interactions with their environment and peers (Schreiber & Valle, 2013). This became evident when students reported during interviews that concept mapping helped them visualize relationships among complex concepts, enhancing their engagement. Additionally, a high-achieving student highlighted the collaborative classroom environment, emphasizing the role of peer interaction in fostering critical thinking and creativity, which aligns with constructivist principles.

In contrast, interview responses from students in the control group revealed limitations of conventional teaching methods, which primarily focused on rote memorization. The difficulties faced by average achievers in solving voltage divider problems underscored a lack of deep understanding. Teachers observed that while students could memorize concepts, they struggled to apply them to complex problems. This disconnect between intended learning outcomes and actual comprehension highlights the need for more interactive and constructivist approaches in the classroom.

Conclusion: *Students in the concept mapping group learned effectively through a process that promoted creativity, ownership, and critical thinking. Visual organization made challenging topics easier to grasp, and collaboration boosted motivation and accomplishment. In contrast, control group students using conventional methods struggled with rote memorization and found it difficult to connect concepts, limiting their critical thinking and problem-solving skills. These findings highlight concept mapping as an effective strategy for enhancing comprehension and enriching the learning experience, thereby supporting the acceptance of the research alternative hypothesis.*

***Research Question 5**: What are the opportunities perceived by teachers and students when using concept mapping?*

This research question centered on how teachers and students perceived the potential benefits of integrating concept mapping into teaching and learning. To answer this, data were collected through interviews and analyzed to understand the opportunities acknowledged by both teachers and students. The study revealed that concept mapping provided significant opportunities in physics education by supporting a range of pedagogical innovations and enhancing the learning experience. The findings revealed several key advantages of concept mapping:

One of the most notable impacts was on expanding pedagogical horizons for teachers, allowing them to utilize concept mapping as a versatile tool that could be effectively applied across subjects and learning contexts. Teachers reported that concept mapping supported various instructional formats, such as group-based mappings, fill-in-the-blank maps, and individual mappings, making it adaptable across different levels and skill sets. This finding, supported by Himangshu (2012), and Sharma et al. (2013), suggested that incorporating various concept mapping activities offered a chance to assess the efficacy of different formats. By incorporating these diverse formats, concept mapping not only accommodated different learning styles but also created a structured yet flexible learning approach, facilitating smoother transitions between complex topics in physics.

Additionally, concept mapping provided valuable insights for teachers into enhancing concept retention among students. Teachers observed that the visual and organizational aspects of concept mapping helped students connect ideas and build a cohesive understanding of physics concepts. The structure of concept mapping also encouraged students to retain information over longer periods, as the repeated association of concepts reinforced memory retention. Furthermore, concept mapping fostered a more dynamic and engaging classroom environment by promoting active participation. Teachers noted that concept mapping exercises encouraged students to take an active role in their learning, as they were more likely to ask questions, seek clarifications, and offer insights during the mapping process. Similar findings in past research Ab Latif (2018), Himangshu (2012), and Motlhabane (2012) revealed students' perceived opportunities while using concept mapping as teachers, contributing insights into seamlessly integrating it into broader instructional strategies and emphasizing its valuable role in creating meaningful learning opportunities in science education.

Concept mapping’s role in fostering collaboration and knowledge-sharing was particularly valued by both teachers and students. Teachers observed that concept mapping activities encouraged students to work together, share ideas, and contribute to a supportive classroom environment. This finding aligned with Kinchin et al. (2005), and Sharma et al. (2013), who observed students learning from each other in small groups during concept mapping. This collaborative approach promoted mutual learning and respect among students, who frequently engaged in constructive discussions and helped each other understand complex concepts. In these group settings, students were not only developing a deeper understanding of physics but also cultivating teamwork skills that contributed to a positive learning atmosphere. By engaging in collaborative concept mapping, students learned to value each other’s perspectives and experiences, creating an inclusive classroom environment that celebrated diversity in thought.

Furthermore, the integration of concept mapping in physics education empowered students by fostering ownership, encouraging self-reflection, and sparking curiosity for a deeper comprehension and increased motivation. In favor of this finding, previous research conducted by Cakiroglu et al. (2022), and Oni et al. (2023) have highlighted the ability to nurture ownership and curiosity, thereby enhancing students' participation with concept mapping.

The study also showed that concept mapping created a stimulating classroom environment, where discussions, debates, and hands-on activities flourished. Teachers noted that concept mapping activities helped reduce passivity among students, as they were more engaged and confident in their understanding of the material. The participatory nature of concept mapping fostered inquiry-based learning, as students were encouraged to ask questions, pursue answers collaboratively, and actively engage with course content. This environment led to greater student engagement and higher levels of enthusiasm for physics, as students felt more connected to the material and to their peers. The results aligned with prior research conducted by Jena (2019), indicating that the use of concept map activities notably improved students' mastery and recall of class material, emphasizing the potential advantages of this active learning approach in fostering a stimulating and effective classroom environment.

The analysis of the responses regarding opportunities presented by concept mapping aligns well with Ausubel's Theory of Meaningful Learning and Constructivism under the philosophy of Pragmatism.

Ausubel's theory emphasized the importance of prior knowledge in facilitating meaningful learning (Ausubel, 1963). Both teachers and students in the experimental group articulated experiences that exemplified this concept. For instance, teachers noted how concept mapping encouraged students to connect new ideas with existing knowledge, leading to a deeper understanding of complex topics like electrical circuits. The reflections of a high-achieving student further illustrated this, as the process of presenting concept maps necessitated clear explanations and justifications of connections, enhancing critical thinking and the ability to relate theoretical knowledge to practical scenarios.

Constructivism, particularly as articulated by Vygotsky, posited that learners construct knowledge actively through interaction with their environment and peers (Schreiber & Valle, 2013). The collaborative aspects highlighted by both teachers and students revealed how concept mapping fostered a sense of ownership and engagement in learning. As students worked together to create and present their concept maps, they not only solidified their understanding but also developed social skills and confidence. This collaborative learning environment facilitated by concept mapping aligns with the principles of constructivism, as students actively engaged in discussions, problem-solving, and inquiry.

Furthermore, the insights from teachers emphasized the versatility of concept mapping as a pedagogical tool, which can be adapted to various subjects and contexts. This adaptability reflects the pragmatic philosophy, which values practical applications of knowledge in real-world situations (Biesta, 2010; James, 2001). Teachers recognized that integrating concept mapping into their teaching practices not only improved student engagement but also bridged the gap between theoretical knowledge and real-life relevance, thereby enhancing the overall learning experience (Wrenn & Wrenn, 2009).

Conclusion: *The exploration of the opportunities perceived by teachers and students through concept mapping highlighted its efficacy as an educational approach that encouraged meaningful learning and active participation. Teachers noted that concept mapping broadened their pedagogical scope, fostered student ownership, and* *created a more engaging learning environment. Likewise, students experienced enhanced confidence, collaboration, and critical thinking skills due to their use of concept maps in their studies. In contrast, feedback from the control group revealed a lack of engagement and real-world applicability in conventional teaching methods, emphasizing the lost opportunities for deeper comprehension in physics education. The analysis confirmed the acceptance of the research alternative hypothesis, as the concept mapping method significantly enhanced both teacher and student experiences, fostering deeper learning and greater engagement.*

***Research Question 6**: What are the challenges encountered by teachers and students when using concept mapping?*

The exploration of the sixth research question utilized qualitative methods. This qualitative inquiry focused on identifying the challenges faced by teachers and students in utilizing concept mapping revealed multifaceted challenges associated with its integration in physics education. Interviews with teachers and students in the experimental group revealed several themes, including perceived difficulty and complexity in creation, linguistic hurdles, struggling with new tools, and demonstrating pedagogical prowess.

Teachers from the experimental group provided valuable insights into the challenges of integrating concept mapping into physics education. One teacher remarked on the ease of representing straightforward relationships but noted the complexity when trying to derive intricate relations. This aligns with previous studies by Dawkins et al. (2008), Harrison and Gibbons (2013), and Kinchin (2014), emphasizing that while concept mapping facilitates understanding in topics with clear connections, it may fall short in addressing complex concepts. This observation highlights that while concept mapping facilitates understanding in topics with clear connections, it may fall short in addressing complex concepts. Consequently, additional strategies might be necessary to convey intricate material effectively.

Another teacher expressed difficulties in combining concept mapping with subjects like circuit diagrams and differential equations, indicating the need for strategic thinking to ensure that concept mapping complemented the overall learning experience without extending the curriculum. This finding, supported by Noor-A-Alam and Mendez (2022) and Machado and Carvalho (2020), highlighted the challenges of effectively presenting and explaining essential course concepts using concept maps, particularly in organizing content and using linking words, ultimately demonstrating the pedagogical skills needed to ensure clarity and comprehensiveness in concept mapping. This concern reflects the challenges of balancing various instructional methods while maintaining student engagement.

Additionally, a third teacher acknowledged the value of concept mapping but pointed out the constraints of a bulky curriculum. Rapid coverage of complex topics, such as Kirchhoff’s law, limited the effective use of concept maps, emphasizing the disconnect between the tool's benefits and the pressures of curriculum requirements.

Students in the experimental group also shared significant challenges. An average achiever emphasized the necessity of thoroughly understanding a topic before constructing a concept map. He indicated that a lack of foundational knowledge hindered his ability to create effective maps, particularly when trying to incorporate complex formulas and mathematical relationships. This finding suggests that scaffolding learning experiences is essential to enable students to engage effectively with concept mapping.

A low-achieving student demonstrated effective coping strategies by creating rough outlines of concept maps and gradually adding details. This approach, combined with the strategic use of colors and shapes, helped clarify the relationships between physics concepts, showcasing how visual differentiation can enhance understanding. This experience was supported by Eshuis et al. (2022), which emphasized that supporting students in the cognitive processes of concept mapping is crucial for effective learning.

Language barriers emerged as another critical challenge. An average-achieving student noted that transitioning from Nepali to English for concept mapping created confusion, making it difficult to comprehend the overall structure. Similarly, a high-achieving student from the control group echoed these sentiments, expressing difficulties in articulating thoughts during class discussions due to a lack of familiarity with English technical terms. These challenges faced by students align with previous research conducted by Chiang (2021), and Kandiko and Hay (2010), who emphasized the vital role of language in education and the necessity of effective language incorporation to improve learning outcomes.

The challenges encountered by teachers and students in using the concept mapping method in physics education can be analyzed through the lenses of Ausubel's Theory of Meaningful Learning and Constructivism within the framework of Pragmatism. Ausubel's theory emphasizes the importance of prior knowledge in learning, positing that new information is more effectively assimilated when it can be related to existing cognitive structures (Ausubel, 2012). The interviews revealed significant obstacles in this regard, particularly in complex topics where students struggled to connect new concepts to their foundational knowledge.

Teachers noted that while concept maps facilitated understanding of straightforward relationships, they faced difficulties with complex concepts like circuit diagrams and differential equations. This aligns with Ausubel's assertion that meaningful learning occurs when learners can integrate new knowledge into their existing cognitive framework (Ausubel, 2012). The lack of adequate cognitive structure hindered students’ ability to fully utilize concept mapping, indicating a need for foundational knowledge before introducing such tools.

Similarly, students from both group expressed challenges rooted in linguistic barriers, with an average-achieving student highlighting the difficulty of transitioning from Nepali to English concepts. This language shift disrupted the cognitive connections necessary for meaningful learning, demonstrating a disconnect between the tools provided and the students' ability to utilize them effectively.

The analysis aligns with the constructivist approach by illustrating how concept mapping facilitates active knowledge construction through student engagement with content (Schreiber & Valle, 2013). Teachers from the experimental group noted challenges in integrating concept mapping with complex topics, such as circuit diagrams and Kirchhoff’s law, highlighting students' struggles to connect abstract concepts with practical diagrams and formulas. Insufficient foundational knowledge and a packed curriculum impede this process. The second low-achieving students’ use of rough outlines and visual differentiation demonstrates adaptability but underscores the need for improved teacher training and curriculum design. This support is crucial for helping students effectively bridge theoretical understanding with real-world applications, maximizing the benefits of concept mapping as a learning tool.

From a pragmatic viewpoint, knowledge is valuable when it leads to practical outcomes (Biesta, 2010; James, 2001). The teachers' and students' experiences underscored the challenge of balancing concept mapping with the curriculum's time constraints, emphasizing the importance of practical teaching tools. For example, the third teacher from the experimental group expressed the difficulty of incorporating concept mapping into a packed syllabus, despite its potential to enhance understanding of voltage, current, and resistance (7:14 ¶ 27 in Interview with teacher from experimental group, 2024). Pragmatically, this situation highlighted the disconnect between concept mapping's theoretical benefits and the practical limitations imposed by the curriculum, reinforcing the need for more adaptable instructional methods.

Conclusion: *Both teachers and students in the experimental group encountered significant challenges with concept mapping in physics due to the complexity of concepts and insufficient foundational knowledge. Students, particularly those with average achievement, struggled to create effective maps because of difficulties with numerical problems, higher-order thinking, language barrier and formula derivation, highlighting a need for improved teacher training. Teachers also faced challenges in integrating concept maps with complex topics while managing a crowded curriculum. The control group similarly experienced time constraints, difficulties in incorporating mathematics into physics lessons, and language barriers. Both groups underscored the necessity for instructional strategies that connected concepts to real-life applications and fostered deeper understanding.*

Research Question 7*: How can we resolve the challenges and promote the opportunities while applying concept mapping method of teaching and learning?*

To address the challenges encountered by both teachers and students in concept mapping for teaching and learning physics, several strategies were implemented:

Perceived Difficulty and Complexity in Creation

Structured training sessions were provided for teachers and students on concept mapping techniques, focusing on hierarchical organization and effective content linkage. Personalized guidance helped to arrange ideas in space and make the maps clearer, reducing confusion.

Linguistic Hurdles

Language incorporation strategies were implemented during concept mapping sessions to facilitate a smooth transition from Nepali to English, ensuring comprehension and clarity.

Struggling with and Coping with New Tools

Ongoing training sessions and workshops were conducted to familiarize teachers and students with various concept mapping tools. Collaborative reflection and discussions were encouraged, utilizing expert examples and reflection prompts to support cognitive processes involved in concept mapping. A student-centered learning environment was fostered, making students comfortable in seeking guidance from teachers and peers. Group discussions addressed confusions during concept map development, promoting dialogue between teachers and students.

Demonstrating Pedagogical Prowess

Specialized training programs were conducted to enhance teachers' pedagogical skills in effectively utilizing concept mapping. The importance of concept mapping was emphasized, encouraging teachers to adjust their teaching methods for better understanding while ensuring lessons were both detailed and concise.

Perceived Difficulties for Teachers

Comprehensive training and ongoing support were provided to teaching staff to address challenges related to research, critical thinking, and precise communication in concept mapping. Optimizing the classroom environment and ensuring topic clarity were prioritized to alleviate perceived difficulties.

These strategies contributed to overcoming the identified challenges and promoting a more effective and positive experience with concept mapping in physics education.

Similarly, to promote the opportunities presented by concept mapping in teaching and learning physics, teachers and institutions considered the following strategies:

Expanding Pedagogical Horizons

Various concept mapping activities, such as fill-in-the-blank maps and collaborative group projects, were incorporated to expand pedagogical approaches. Different concept mapping formats were assessed to cater to diverse learning styles, enhancing overall comprehension.

Teaching Insights with Concept Mapping

Concept mapping was integrated into teaching physics to enrich instructional experiences and enhance student comprehension. By actively involving students in the learning process, concept mapping facilitated a deeper understanding of complex concepts, leading to increased classroom engagement. For teachers, the method proved valuable in improving instructional techniques, enabling more effective and interactive lessons.

Fostering Collaboration through Comprehensive Concept Mapping

Collaborative efforts, diverse perspectives, and effective communication were encouraged among students through concept mapping. Platforms were provided for addressing peers' questions and engaging in discussions, deepening comprehension of complex topics.

Empowering Ownership and Curiosity

The empowering aspects of concept mapping were emphasized, fostering ownership, self-reflection, and curiosity among students. Concept mapping was recognized as a tool that enhanced student engagement and nurtured curiosity, leading to a more proactive learning approach.

Creating an Engaging Classroom Environment

Concept mapping was utilized to foster a positive classroom environment, active participation, and effective learning experiences. Discussions facilitated by concept mapping clarified concepts, instilled confidence, and integrated practical-based learning.

The identification of these strategies was based on a combination of classroom observations, interviews with teachers and students, and structured orientation sessions conducted by the researcher. Observations provided insights into how students engaged with concept mapping activities, while interviews captured their experiences, challenges, and perceived benefits. Additionally, orientation sessions played a crucial role in familiarizing teachers and students with various concept mapping techniques, ensuring effective implementation. Thus, by implementing these strategies, educators maximized the potential opportunities offered by concept mapping, creating a more engaging, collaborative, and effective learning environment in physics education.

In the realm of classroom observations and reflective behavior checklists, the strategies implemented to tackle challenges and harness opportunities in concept mapping for teaching and learning physics yielded positive outcomes. Students actively participated in class, demonstrated initiative in approaching assignments, and disruptive behavior significantly reduced with the structured training. Inattentive behavior transformed into increased awareness, reflecting the effectiveness of coping strategies. Reflective behavior checklists indicated notable improvements, with students excelling in creating inquiries, critically diagnosing errors, and actively engaging in collaborative activities. These outcomes underscore the success of the multifaceted approach, emphasizing tailored strategies to address challenges and promote opportunities in concept mapping for physics education (Self-reflection of researcher, 2024).

The integration of Ausubel's Theory of Meaningful Learning and Constructivist Learning Theory, framed within the philosophy of pragmatism, was evident in these positive outcomes. Pragmatism, which prioritizes the practical application of knowledge and continuous learning through experience, informed the approach to addressing the difficulties associated with concept mapping (Wrenn & Wrenn, 2009). The strategies led to more engaged student participation, greater initiative in completing assignments, and a significant decline in disruptive behavior through structured training. The shift from inattentiveness to heightened awareness reflected the effectiveness of these coping mechanisms, aligning with Ausubel's focus on meaningful learning. Furthermore, the improvements documented in reflective behavior checklists—such as students' enhanced ability to create inquiries, critically assess errors, and collaborate effectively—reinforced the principles of Constructivist learning.

Conclusion: *Teachers addressed concept mapping challenges by offering training, incorporating language support, and fostering collaboration. They engaged students with varied activities and enhanced teaching methods to deepen understanding and boost engagement. These strategies resolved difficulties and maximized concept* *mapping's potential, creating a more effective and interactive physics learning environment.*

Summary

This chapter explored the findings and discussions regarding the effectiveness of the concept mapping method on students' achievement in science education, particularly at the bachelor level in physics. The study was guided by five objectives and seven research questions, focusing on the impact of concept mapping on academic performance, learning strategies, and the opportunities and challenges faced by students and teachers.

The researcher utilized various methods to implement concept mapping in physics education, analyzing achievement test scores from both control and experimental groups using SPSS version 20. Key statistical measures were calculated, including mean, standard deviation, and significance values. The findings, derived from both quantitative and qualitative data, were systematically organized to address the research questions, revealing insights into effective learning through concept mapping, perceived opportunities, and encountered challenges.

The chapter emphasized the need for strategies to overcome these challenges while fostering the advantages of concept mapping in teaching and learning. The findings were contextualized within relevant theoretical frameworks, including the philosophy of pragmatism, which underpinned the practical application of knowledge. Additionally, The chapter integrated Ausubel's Meaningful Learning Theory and Constructivism, highlighting their support for concept mapping's benefits in student engagement and understanding, further validated by empirical evidence with implications for education and future research.

Chapter VI

Conclusions and Implications

Introduction

This chapter succinctly concludes the research endeavors, exploring the implications derived from various concept mapping procedures in physics education. Addressing learning strategies, opportunities, and challenges in leveraging concept mapping for enhanced learning, the chapter draws conclusions based on research questions. Practical insights are offered to educators, highlighting the effectiveness of concept mapping and facilitating the connection between theoretical concepts and their application in physics education.

Conclusion

This study concluded that the concept mapping method significantly enhanced students' achievement in physics, with the experimental group outperforming the control group in post-test scores. The method improved students' performance across cognitive domains, particularly in Knowledge and Understanding, although challenges persisted in the Application and Higher-Level domains. While both genders started with similar cognitive abilities, male students performed better at higher cognitive levels, highlighting a gender performance gap.

Beyond achievement, concept mapping effectively fostered critical thinking, creativity, and student ownership of learning. Students were highly motivated and engaged, especially when creating personalized concept maps. Teachers also benefited from the method’s versatility, which supported varied instructional strategies and collaborative learning environments.

This study contributes new knowledge on the effectiveness of concept mapping in physics education in the Nepalese context, demonstrating its impact on student achievement, engagement, and conceptual understanding. By integrating concept mapping into teaching strategies, teachers can foster a more interactive, meaningful, and student-centered learning experience. This approach enables teachers to make lessons more interactive, identify misconceptions early, and encourage collaborative learning among students. In terms of learning, concept mapping enhances conceptual understanding, promotes critical thinking and problem-solving in science, and improves long-term retention of knowledge. Additionally, it serves as a valuable formative assessment tool, providing a visual representation of students' thinking processes and offering deeper insights into their conceptual grasp. Furthermore, the study provides insights for future research on optimizing concept mapping for diverse learners and subject areas.

However, challenges arose, including difficulties in map creation, linguistic issues, and the need for improved pedagogical skills. Addressing these challenges requires continuous training and professional development for both teachers and students. Despite these difficulties, concept mapping significantly enhanced the learning experience, fostering a more dynamic, engaging, and effective educational environment in physics.

Pedagogical and administrative implication of research

This research was based on a quasi-experimental design which required careful control of various variables to minimize threats to internal validity. It was also important to manage extraneous variables that could impact external validity to enhance the broader applicability of the findings. The methods used to control these variables were described in earlier chapter.

Several measures were implemented to enhance both the internal and external validity of the research. This involved the meticulous control of extraneous variables through various mechanisms, as expounded in Chapter Three. The researcher executed experimental procedures, signifying a substantial impact in the realm of teaching and learning science across educational levels, ranging from schools to universities. The diverse implications of the research are discussed below:

Implication for practice level

Implication for Students

This study involved students directly in research activities. Classroom teaching, participation in various co-curricular activities, students' presentations, and interactive and joint work development with students and teachers constituted key aspects of this research. The research encompassed both formal and informal interactions with students. It involved interviews with low, medium, and high-performing students, exploring their learning activities.

Moreover, students found the concept mapping technique extendable to other areas of learning. Many students expressed that the skills they developed through concept mapping were applicable to subjects outside physics, showing the method’s broad potential for enhancing learning in various disciplines. This transferability suggests that the benefits of concept mapping extend beyond a single subject, providing students with valuable tools for organizing and processing knowledge across different contexts.

An important aspect highlighted by students was the value of collaborative learning and teamwork. The concept mapping method inherently fostered team work, enabling students to exchange ideas and assist one another in the learning process. Students reported that the collaborative aspect not only helped them understand the material better but also cultivated a sense of community and mutual encouragement.

This collaborative learning environment empowered students to take ownership of their learning and engage with peers in ways that deepened their understanding.

In light of these positive experiences, students expressed interest in expanding the use of concept mapping beyond the classroom, with some suggesting its integration into other subjects or institutional activities. This indicates that students not only appreciated the method but also saw its broader potential in enhancing the overall learning environment at the institution. The study’s implications for students suggest that concept mapping can play a significant role in fostering cognitive skills, promoting collaborative learning, and expanding the boundaries of learning into other disciplines and settings.

Implication for the teachers

The findings from this research provided valuable insights into how concept mapping differed from conventional teaching methods, particularly from the teacher's perspective. Teaching physics through concept mapping required a more active and engaged role compared to conventional methods. Unlike conventional approaches that relied on direct instruction and rote memorization, the concept mapping method necessitated facilitating deeper cognitive engagement and active participation from students. This shift involved moving from merely delivering content to fostering an environment where students could visualize and connect complex physics concepts.

As a tool, concept mapping served as a powerful visual aid, enabling teachers to guide students in constructing and organizing knowledge in a more structured manner. The method allowed for the visualization of relationships between different physics concepts, making it easier for students to understand and retain information. This approach differed significantly from the linear, text-based methods typically used in conventional teaching, which often limited students' ability to see the broader picture and connect new concepts with prior knowledge.

Implementing concept mapping involved additional preparation and a willingness to adopt innovative teaching strategies. Teachers needed to develop and use concept maps that were not only accurate and holistic but also adaptable to different learning styles and levels of understanding. This required a deeper understanding of both the subject matter and the cognitive processes involved in learning, as well as the ability to create and modify concept maps in response to students' needs.

Furthermore, the research highlighted the importance of teachers as both researchers and practitioners. Incorporating concept mapping into teaching actively contributed to the development of students' cognitive skills, particularly in understanding and applying physics concepts. The method proved to be more effective than conventional teaching at the bachelor level, as evidenced by the improved performance of students taught using concept mapping.

Implication for policy level

The findings of this study underscore the potential of concept mapping to enhance student engagement and learning outcomes in science education. Policymakers and curriculum developers should consider integrating concept mapping into science curricula at various educational levels, from primary to higher education. To ensure its effective implementation, teacher training programs should emphasize concept mapping methods, equipping teachers with the skills to facilitate meaningful learning. Additionally, assessment methods should shift from rote memorization to evaluating students’ conceptual understanding. Since this study was limited to the bachelor level, further research across different educational levels is necessary to validate and expand these findings, providing a stronger basis for policy decisions.

Implication for further research

This study was conducted at two constituent colleges in the Kathmandu and Bhaktapur districts. Expanding this study to a national scale would yield more valid and reliable insights into the impact of concept mapping across diverse educational contexts and populations. Future research could investigate the long-term effects of concept mapping across different science subjects, age groups, and educational levels, as well as address the gender gap in achievement. Additionally, exploring the impact on underperforming student groups, including socially disadvantaged students, would provide valuable insights into how concept mapping can help bridge educational disparities. Extending the intervention period and exploring the combination of concept mapping with other strategies could further support the development of higher-order thinking and complex problem-solving skills. While this study focused on the cognitive impact of concept mapping, future research could also explore how social interactionism enhances collaborative learning through concept mapping. Investigating peer discussions, group-based concept mapping, and teacher-student interactions would offer deeper insights into how knowledge is co-constructed in a classroom setting. Moreover, integrating digital tools into concept mapping could enhance its effectiveness and accessibility, potentially improving learning outcomes.

Way Out for More Research

This research laid the groundwork for further exploration by identifying key directions for future investigations. The study focused specifically on the domain of electricity within the broader field of physics. However, this approach could be extended to other branches of science, such as chemistry, biology, and earth science, offering opportunities to explore the effectiveness of concept mapping in diverse scientific disciplines. Each of these fields presents unique concepts and challenges that could benefit from the structured visual representation and cognitive engagement provided by concept mapping.

Additionally, similar research could be conducted with students from colleges outside the Kathmandu Valley, particularly in rural areas of Nepal, to broaden the scope and applicability of the findings. Due to constraints related to time and resources, this study was limited to two colleges—one serving as the experimental group and the other as the control group. Expanding the research to include more schools and colleges could provide a more comprehensive understanding and yield more generalizable results.

My Reflection in my Ph.D. Journey

Embarking on the challenging journey of a Ph.D., I experienced moments of joy and excitement intertwined with various challenges. Recalling my humble beginnings in a medium-class family in a village in Dhanusha District, where I was the youngest among six siblings, my early education lacked facilities. However, my interest in science blossomed during my school days. The conventional learning methods persisted through my college and master's degree, sparking my curiosity about innovative approaches to teaching science. As I transitioned into teaching at the college level, I experimented with improvised materials and field visits to bridge theory with real-life application, particularly focusing on the challenging subject of physics.

This pursuit of effective teaching methods led me to explore new approaches, intensifying as students faced difficulties in learning physics. The Ph.D. journey brought its share of challenges, yet I successfully completed assigned tasks within the stipulated time after the temporary registration of my Ph.D. project. Tasks included seminar paper preparation, literature review, and formulating the final proposal, followed by its defense. The subsequent permanent registration marked a significant milestone.

However, the journey faced unexpected challenges, notably the nationwide COVID-19 lockdown, delaying fieldwork and data collection in sample colleges. Navigating this unprecedented situation, I patiently awaited opportunities to conduct research. The dedication to an honest and hardworking environment propelled the journey forward, showcasing resilience and determination in pursuing a Ph.D. These experiences, both challenging and rewarding, have been integral to shaping my Ph.D. trajectory.

In investigating the " Concept Mapping Method on Students' Achievement in Science Education at Higher Level," the study employed a pretest-posttest non-equivalent group design, meticulously defining research variables and ensuring robust validity measures. Ethical considerations embodied a sincere commitment to safeguarding participants' rights. The integration of SPSS for quantitative analysis and ATLAS.ti 9 for qualitative insights facilitated a detailed exploration. Beyond academic findings, this research journey provided invaluable insights into methodologies and the intricate dynamics of educational interventions.

Ethical Consideration

The researcher swore to protect the welfare of those who participated in the research and to avoid any negative outcomes in accordance with ethical standards. Throughout the research process, this commitment included a focus on multiple important ethical aspects.

First of all, the idea of informed consent was strictly adhered to, guaranteeing that before giving their assent to participate, participants were fully informed about the purpose and nature of the study. The significance of acceptability and access, along with honoring people's freedom to refuse study participation, was also emphasized by the researcher. Participant privacy was protected by putting in place the necessary safeguards and guaranteeing the confidentiality of participant information. Ensuring that the research findings will not divulge the identities of certain individuals was a fundamental criterion upheld. According to Cohen et al. (2007b), the researcher was committed to respecting the principles of secrecy, non-betrayal, and no deception. As a result, all data collected for the study was handled with the highest confidentiality, utilized only for legitimate academic reasons, and protected from betrayal.

Summary

This chapter explored the conclusions and implications of using the concept mapping method in physics education. The findings indicated that concept mapping significantly enhanced students' academic achievement, fostering deeper understanding and critical thinking skills compared to traditional teaching approaches. Participants expressed increased motivation and engagement, highlighting the method's ability to promote active learning and collaboration. However, challenges were noted, including difficulties in applying knowledge at higher cognitive levels and linguistic barriers among students. Additionally, a notable gender performance gap emerged, with male students generally outperforming female counterparts. The chapter underscored the importance of providing adequate training and resources for teachers to effectively implement concept mapping in their classrooms. It emphasized the potential of this instructional strategy to be integrated into various curricula, suggesting further research in diverse educational contexts to evaluate its effectiveness in different scientific disciplines. The reflections on the research journey also highlighted the significance of perseverance and adaptability in pursuing innovative teaching methodologies in science education.

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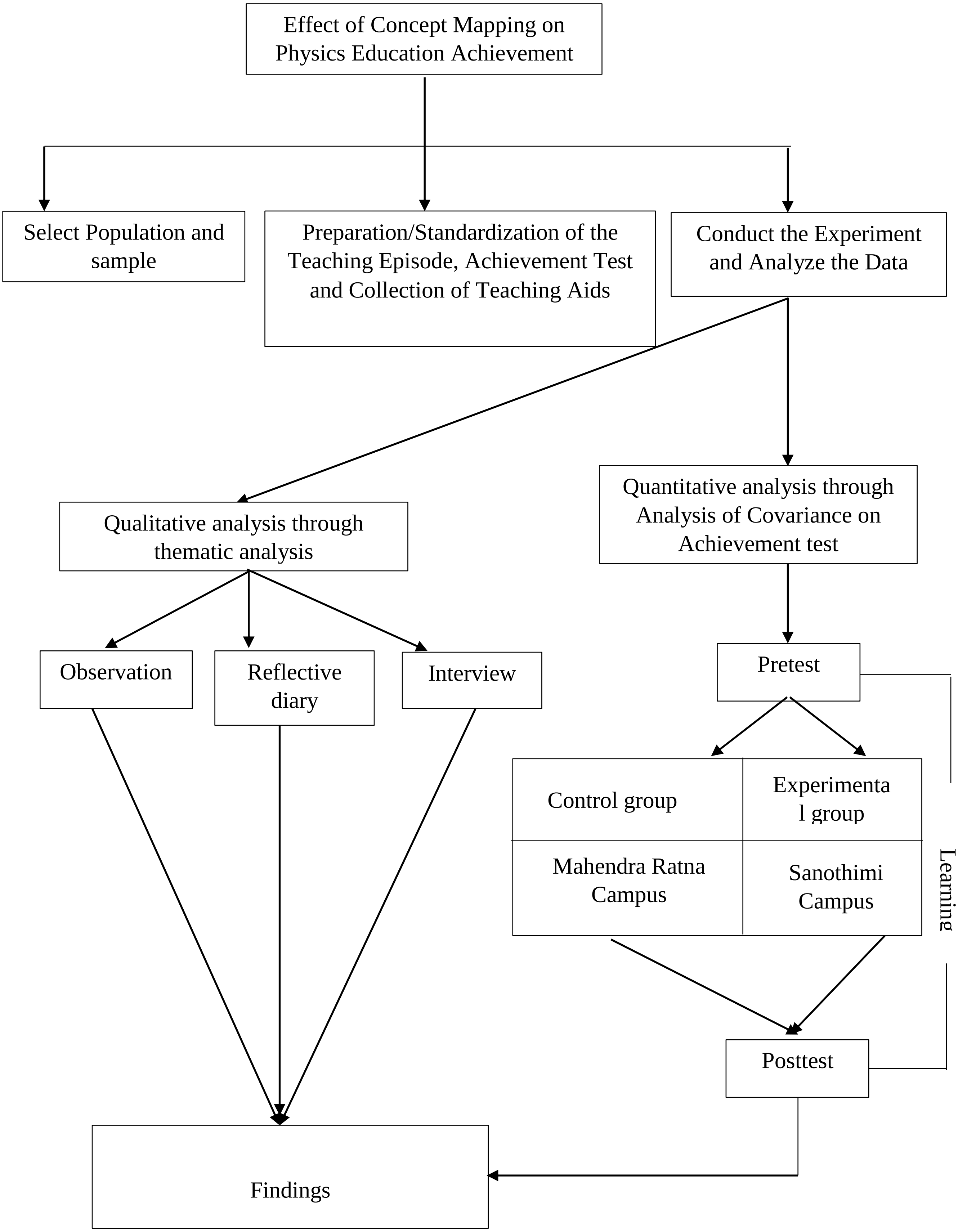
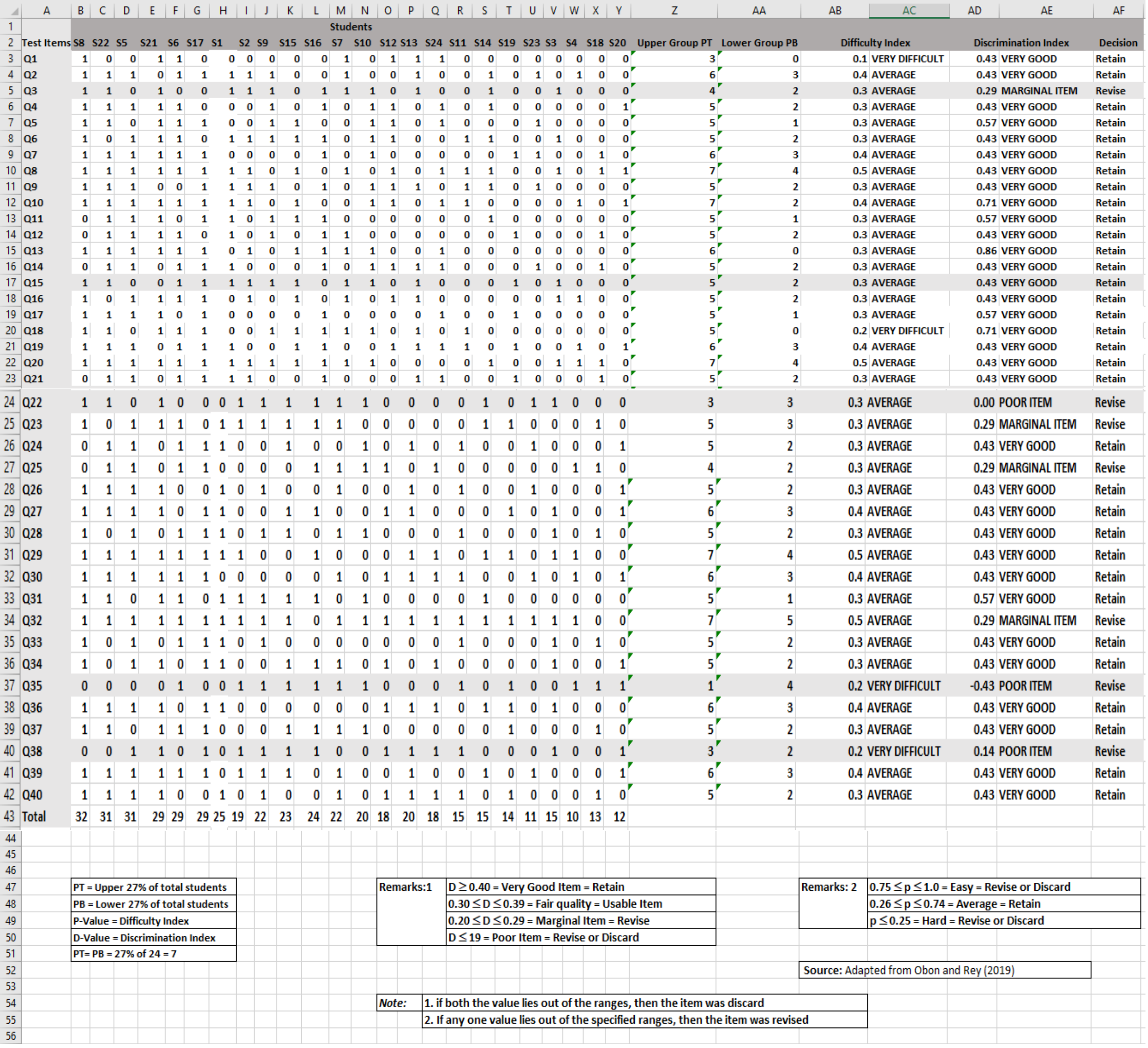
APPENDICES

Appendix I: Schematic diagram for analyzing the present study



Appendix II: Item Analysis Chart for Pretest Items



	Students																														
Test Items	S8	S22	S5	S21	S6	S17	S1	S2	S9	S15	S16	S7	S10	S12	S13	S24	S11	S14	S19	S23	S3	S4	S18	S20	Upper Group PT	Lower Group PB	Difficulty Index		Discrimination Index		Decision
Q1	1	0	0	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	3	0	0.1	VERY DIFFICULT	0.43	VERY GOOD	Retain
Q2	1	1	1	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	0	0	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q3	1	1	0	1	0	0	1	1	1	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0	4	2	0.3	AVERAGE	0.29	MARGINAL ITEM	Revise
Q4	1	1	1	1	1	0	0	0	1	0	1	0	1	1	0	1	0	1	0	0	0	0	0	1	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q5	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1	0	0	0	1	0	0	0	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q6	1	0	1	1	1	0	1	1	1	1	1	0	1	1	0	0	1	1	0	0	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q7	1	1	1	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0	0	1	0	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q8	1	1	1	1	1	1	1	1	0	1	0	1	0	1	0	1	1	1	0	0	1	0	1	1	7	4	0.5	AVERAGE	0.43	VERY GOOD	Retain
Q9	1	1	1	0	0	1	1	1	1	0	1	0	1	1	1	0	1	1	0	1	0	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q10	1	1	1	1	1	1	1	1	0	1	0	0	1	1	0	1	1	0	0	0	0	1	0	1	7	2	0.4	AVERAGE	0.71	VERY GOOD	Retain
Q11	0	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q12	0	1	1	1	1	0	1	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q13	1	1	1	1	1	1	0	1	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	6	0	0.3	AVERAGE	0.86	VERY GOOD	Retain
Q14	0	1	1	0	1	1	1	0	0	0	1	0	1	1	1	1	0	0	0	1	0	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q15	1	1	0	0	1	1	1	1	1	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q16	1	0	1	1	1	1	0	1	0	1	0	1	0	1	1	0	0	0	0	0	1	1	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q17	1	1	1	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q18	1	1	0	1	1	1	0	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	5	0	0.2	VERY DIFFICULT	0.71	VERY GOOD	Retain
Q19	1	1	1	0	1	1	1	0	0	1	1	0	0	1	1	1	1	0	1	0	0	1	0	1	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q20	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	1	1	1	0	7	4	0.5	AVERAGE	0.43	VERY GOOD	Retain
Q21	0	1	1	0	1	1	1	1	0	0	1	0	0	0	1	1	0	0	1	0	0	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q22	1	1	0	1	0	0	0	1	1	1	1	1	1	0	0	0	0	1	0	1	1	0	0	0	3	3	0.3	AVERAGE	0.00	POOR ITEM	Revise
Q23	1	0	1	1	1	0	1	1	1	1	1	1	0	0	0	0	0	1	1	0	0	0	1	0	5	3	0.3	AVERAGE	0.29	MARGINAL ITEM	Revise
Q24	0	1	1	0	1	1	1	0	0	1	0	0	1	0	1	0	1	0	0	1	0	0	0	1	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q25	0	1	1	0	1	1	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	1	1	0	4	2	0.3	AVERAGE	0.29	MARGINAL ITEM	Revise
Q26	1	1	1	1	0	0	1	0	1	0	0	1	0	0	1	0	1	0	0	1	0	0	0	1	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q27	1	1	1	1	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	1	0	0	1	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q28	1	0	1	0	1	1	1	0	1	1	0	1	1	0	0	0	1	0	0	0	1	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q29	1	1	1	1	1	1	1	1	0	0	1	0	0	0	1	1	0	1	1	0	1	1	0	0	7	4	0.5	AVERAGE	0.43	VERY GOOD	Retain
Q30	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	1	1	0	0	1	0	1	0	1	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q31	1	1	0	1	1	0	1	1	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q32	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	7	5	0.5	AVERAGE	0.29	MARGINAL ITEM	Revise
Q33	1	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q34	1	0	1	1	0	1	1	0	0	1	1	1	0	1	0	1	0	0	0	0	1	0	0	1	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q35	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1	1	1	4	0.2	VERY DIFFICULT	-0.43	POOR ITEM	Revise
Q36	1	1	1	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	0	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q37	1	1	0	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q38	0	0	1	1	0	1	0	1	1	1	1	0	0	1	1	1	1	0	0	0	1	0	0	1	3	2	0.2	VERY DIFFICULT	0.14	POOR ITEM	Revise
Q39	1	1	1	1	1	1	0	1	1	1	0	1	0	0	1	0	0	1	0	1	0	0	0	1	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q40	1	1	1	1	0	0	1	0	1	0	0	1	0	1	1	1	1	0	1	0	0	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Total	32	31	31	29	29	29	25	19	22	23	24	22	20	18	20	18	15	15	14	11	15	10	13	12							

PT = Upper 27% of total students
PB = Lower 27% of total students
P-Value = Difficulty Index
D-Value = Discrimination Index
PT= PB = 27% of 24 = 7

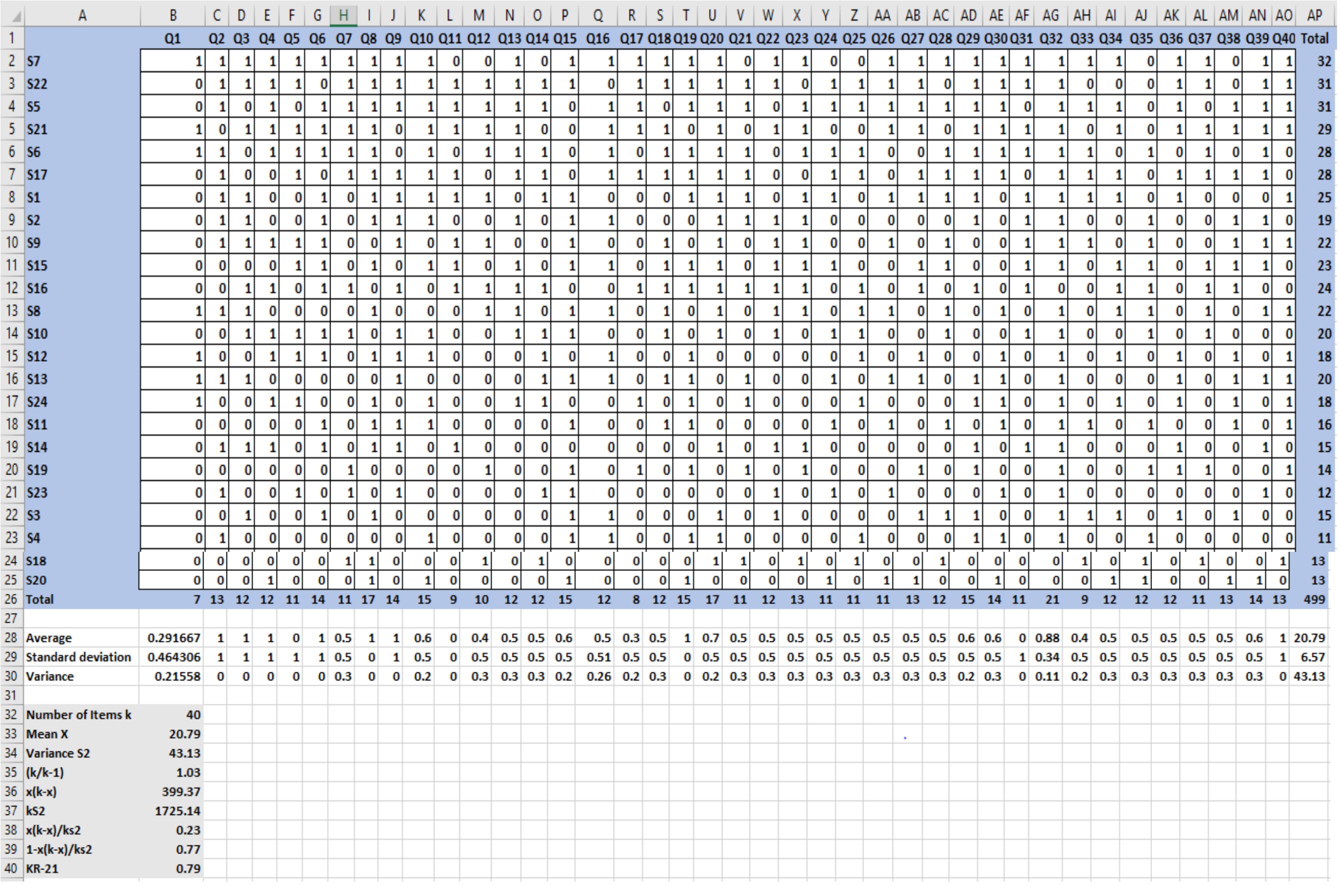
Remarks:1
D ≥ 0.40 = Very Good Item = Retain
0.30 ≤ D ≤ 0.39 = Fair quality = Usable Item
0.20 ≤ D ≤ 0.29 = Marginal Item = Revise
D ≤ 19 = Poor Item = Revise or Discard

Remarks: 2
0.75 ≤ p ≤ 1.0 = Easy = Revise or Discard
0.26 ≤ p ≤ 0.74 = Average = Retain
p ≤ 0.25 = Hard = Revise or Discard

Source: Adapted from Obon and Rey (2019)

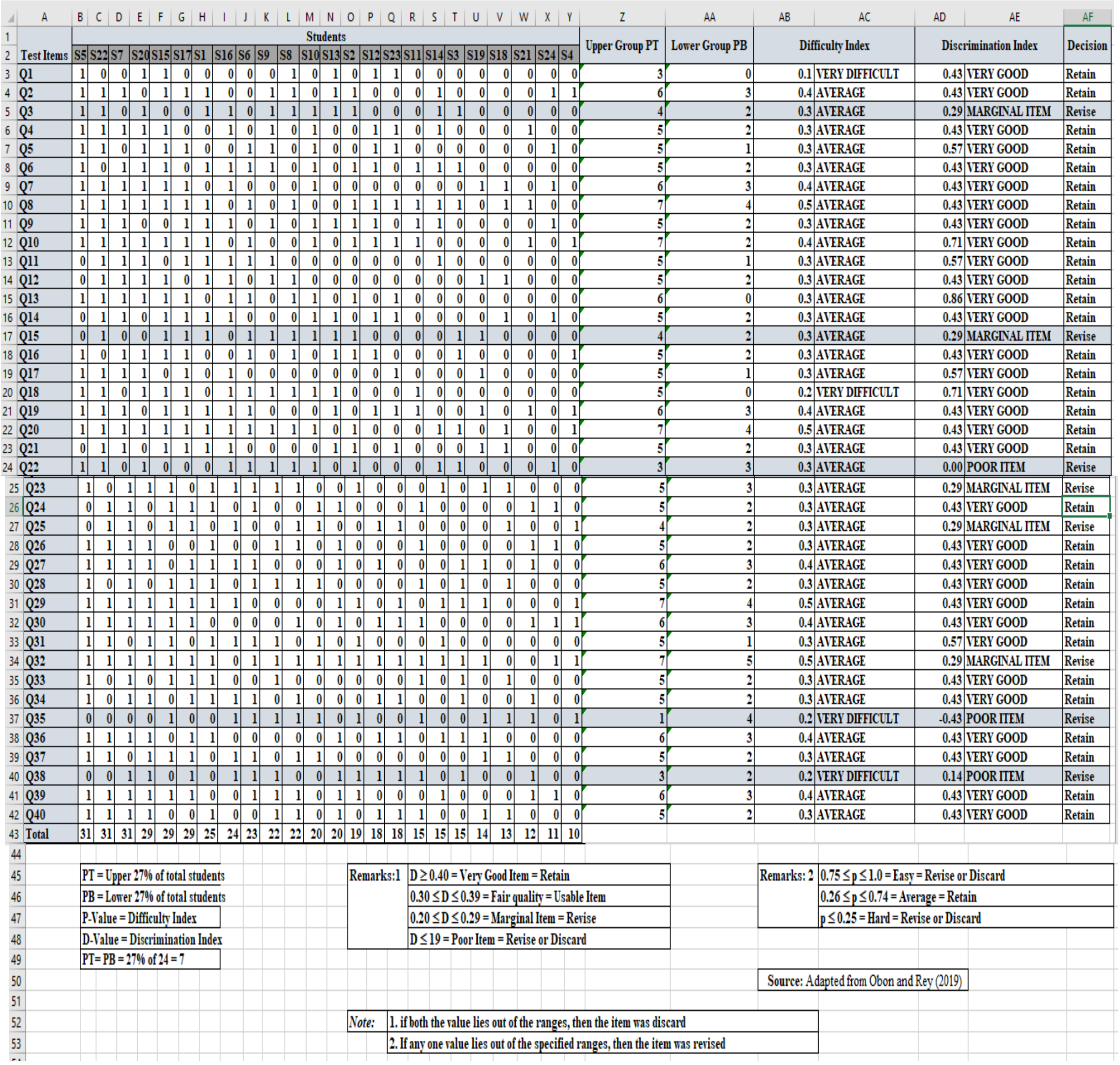
Note:
1. if both the value lies out of the ranges, then the item was discard
2. If any one value lies out of the specified ranges, then the item was revised

Appendix III: Reliability Test for Pretest Items



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
1		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32	Q33	Q34	Q35	Q36	Q37	Q38	Q39	Q40	Total
2	S7	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	32
3	S22	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	0	0	1	1	0	1	1	31
4	S5	0	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	1	31
5	S21	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	0	1	0	1	1	0	0	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	29
6	S6	1	1	0	1	1	1	1	1	0	1	0	1	1	1	0	1	0	1	1	1	1	0	1	1	1	0	0	1	1	1	1	1	1	0	1	0	1	0	1	0	28
7	S17	0	1	0	0	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1	0	28
8	S1	0	1	1	0	0	1	0	1	1	1	1	1	0	1	1	0	0	0	1	1	1	0	1	1	0	1	1	1	1	0	1	1	1	1	0	1	0	0	0	1	25
9	S2	0	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	0	0	0	1	1	1	1	0	0	0	0	0	1	0	1	1	0	0	1	0	0	1	1	0	19
10	S9	0	1	1	1	1	1	0	0	1	0	1	1	0	0	1	0	0	1	0	1	0	1	1	0	0	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	22
11	S15	0	0	0	0	1	1	0	1	0	1	1	0	1	0	1	1	0	1	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1	1	0	1	1	1	0	23
12	S16	0	0	1	1	0	1	1	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	0	1	0	1	0	1	0	0	1	1	0	1	1	0	0	24
13	S8	1	1	1	0	0	0	0	1	0	0	0	1	1	0	1	1	0	1	0	1	0	1	1	0	1	1	0	1	0	1	0	1	0	1	1	0	1	0	1	1	22
14	S10	0	0	1	1	1	1	1	0	1	1	0	0	1	1	1	0	0	1	0	1	0	1	0	1	1	0	0	1	0	0	1	1	0	0	1	0	1	0	0	0	20
15	S12	1	0	0	1	1	1	0	1	1	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	1	0	1	0	1	0	1	0	1	18
16	S13	1	1	1	0	0	0	0	0	1	0	0	0	0	1	1	1	0	1	1	0	1	0	0	1	0	1	1	0	1	1	0	1	0	0	0	1	0	1	1	1	20
17	S24	1	0	0	1	1	0	0	1	0	1	0	0	1	1	0	0	1	0	1	0	1	0	0	0	1	0	0	0	1	1	0	1	0	1	0	1	0	1	0	1	18
18	S11	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	0	0	1	1	0	0	0	0	1	0	1	0	1	0	1	0	1	1	0	1	0	0	1	0	1	16
19	S14	0	1	1	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	1	0	15
20	S19	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	1	0	0	1	0	0	1	1	1	0	0	1	14
21	S23	0	1	0	0	1	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	12
22	S3	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	0	1	0	1	0	0	15
23	S4	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	1	1	0	0	0	0	1	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	11
24	S18	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	0	1	0	1	0	1	0	0	1	13
25	S20	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	1	1	0	0	1	0	0	0	1	1	0	0	1	1	0	13
26	Total	7	13	12	12	11	14	11	17	14	15	9	10	12	12	15	12	8	12	15	17	11	12	13	11	11	11	13	12	15	14	11	21	9	12	12	12	11	13	14	13	499
27																																										
28	Average	0.291667	1	1	1	0	1	0.5	1	1	0.6	0	0.4	0.5	0.5	0.6	0.5	0.3	0.5	1	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0	0.88	0.4	0.5	0.5	0.5	0.5	0.5	0.6	1	20.79
29	Standard deviation	0.464306	1	1	1	1	1	0.5	0	1	0.5	0	0.5	0.5	0.5	0.5	0.51	0.5	0.5	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.34	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	6.57
30	Variance	0.21558	0	0	0	0	0	0.3	0	0	0.2	0	0.3	0.3	0.3	0.2	0.26	0.2	0.3	0	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0	0.11	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0	43.13
31																																										
32	Number of Items k	40																																								
33	Mean X	20.79																																								
34	Variance S2	43.13																																								
35	(k/k-1)	1.03																																								
36	x(k-x)	399.37																																								
37	kS2	1725.14																																								
38	x(k-x)/ks2	0.23																																								
39	1-x(k-x)/ks2	0.77																																								
40	KR-21	0.79																																								

Appendix IV: Item Analysis Chart for Posttest Items



Test Items	Students																								Upper Group PT	Lower Group PB	Difficulty Index		Discrimination Index		Decision
	S5	S22	S7	S20	S15	S17	S1	S16	S6	S9	S8	S10	S13	S2	S12	S23	S11	S14	S3	S19	S18	S21	S24	S4							
Q1	1	0	0	1	1	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	3	0	0.1	VERY DIFFICULT	0.43	VERY GOOD	Retain
Q2	1	1	1	0	1	1	1	0	0	1	1	0	1	1	0	0	0	1	0	0	0	0	1	1	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q3	1	1	0	1	0	0	1	1	0	1	1	1	1	1	0	0	0	1	1	0	0	0	0	0	4	2	0.3	AVERAGE	0.29	MARGINAL ITEM	Revise
Q4	1	1	1	1	1	0	0	1	0	1	0	1	0	0	1	1	0	1	0	0	0	1	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q5	1	1	0	1	1	1	0	0	1	1	0	1	0	0	1	1	0	0	0	0	0	0	1	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q6	1	0	1	1	1	0	1	1	1	1	0	1	0	1	1	0	1	1	1	0	0	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q7	1	1	1	1	1	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	1	0	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q8	1	1	1	1	1	1	1	0	1	0	1	0	0	1	1	1	1	1	1	0	1	1	0	0	7	4	0.5	AVERAGE	0.43	VERY GOOD	Retain
Q9	1	1	1	0	0	1	1	1	0	1	0	1	1	1	1	0	1	1	0	0	0	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q10	1	1	1	1	1	1	1	0	1	0	0	1	0	1	1	1	1	0	0	0	0	1	0	1	7	2	0.4	AVERAGE	0.71	VERY GOOD	Retain
Q11	0	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q12	0	1	1	1	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q13	1	1	1	1	1	1	0	1	1	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	6	0	0.3	AVERAGE	0.86	VERY GOOD	Retain
Q14	0	1	1	0	1	1	1	1	0	0	0	1	1	0	1	1	0	0	0	0	1	0	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q15	0	1	0	0	1	1	1	0	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	4	2	0.3	AVERAGE	0.29	MARGINAL ITEM	Revise
Q16	1	0	1	1	1	1	0	0	1	0	1	0	1	1	1	0	0	0	1	0	0	0	0	1	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q17	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q18	1	1	0	1	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	5	0	0.2	VERY DIFFICULT	0.71	VERY GOOD	Retain
Q19	1	1	1	0	1	1	1	1	1	0	0	0	1	0	1	1	1	0	0	1	0	1	0	1	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q20	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	1	1	0	1	0	0	1	7	4	0.5	AVERAGE	0.43	VERY GOOD	Retain
Q21	0	1	1	0	1	1	1	1	0	0	0	0	1	1	0	1	0	0	0	1	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q22	1	1	0	1	0	0	0	1	1	1	1	1	0	1	0	0	0	1	1	0	0	0	1	0	3	3	0.3	AVERAGE	0.00	POOR ITEM	Revise
Q23	1	0	1	1	1	0	1	1	1	1	1	0	0	1	0	0	0	1	0	1	1	0	0	0	5	3	0.3	AVERAGE	0.29	MARGINAL ITEM	Revise
Q24	0	1	1	0	1	1	1	0	1	0	0	1	1	0	0	0	1	0	0	0	0	1	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q25	0	1	1	0	1	1	0	1	0	0	1	1	0	0	1	1	0	0	0	0	1	0	0	1	4	2	0.3	AVERAGE	0.29	MARGINAL ITEM	Revise
Q26	1	1	1	1	0	0	1	0	0	1	1	0	1	0	0	0	1	0	0	0	0	1	1	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q27	1	1	1	1	0	1	1	1	1	0	0	0	1	0	1	0	0	0	1	1	0	1	0	0	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q28	1	0	1	0	1	1	1	0	1	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q29	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	1	0	1	1	1	0	0	0	1	7	4	0.5	AVERAGE	0.43	VERY GOOD	Retain
Q30	1	1	1	1	1	1	0	0	0	0	1	0	1	0	1	1	1	0	0	0	0	1	1	1	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q31	1	1	0	1	1	0	1	1	1	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	5	1	0.3	AVERAGE	0.57	VERY GOOD	Retain
Q32	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	7	5	0.5	AVERAGE	0.29	MARGINAL ITEM	Revise
Q33	1	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q34	1	0	1	1	0	1	1	1	1	0	1	0	0	0	1	1	0	0	1	0	0	1	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q35	0	0	0	0	1	0	0	1	1	1	1	1	0	1	0	0	1	0	0	1	1	1	0	1	1	4	0.2	VERY DIFFICULT	-0.43	POOR ITEM	Revise
Q36	1	1	1	1	0	1	1	0	0	0	0	0	1	0	1	1	0	1	1	1	0	0	0	0	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q37	1	1	0	1	1	1	0	1	1	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Q38	0	0	1	1	0	1	0	1	1	1	0	0	1	1	1	1	1	0	1	0	0	1	0	0	3	2	0.2	VERY DIFFICULT	0.14	POOR ITEM	Revise
Q39	1	1	1	1	1	1	0	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1	1	0	6	3	0.4	AVERAGE	0.43	VERY GOOD	Retain
Q40	1	1	1	1	0	0	1	0	0	1	1	0	1	0	1	1	1	0	0	1	1	0	0	0	5	2	0.3	AVERAGE	0.43	VERY GOOD	Retain
Total	31	31	31	29	29	29	25	24	23	22	22	20	20	19	18	18	15	15	15	14	13	12	11	10							

PT = Upper 27% of total students
PB = Lower 27% of total students
P-Value = Difficulty Index
D-Value = Discrimination Index
PT= PB = 27% of 24 = 7

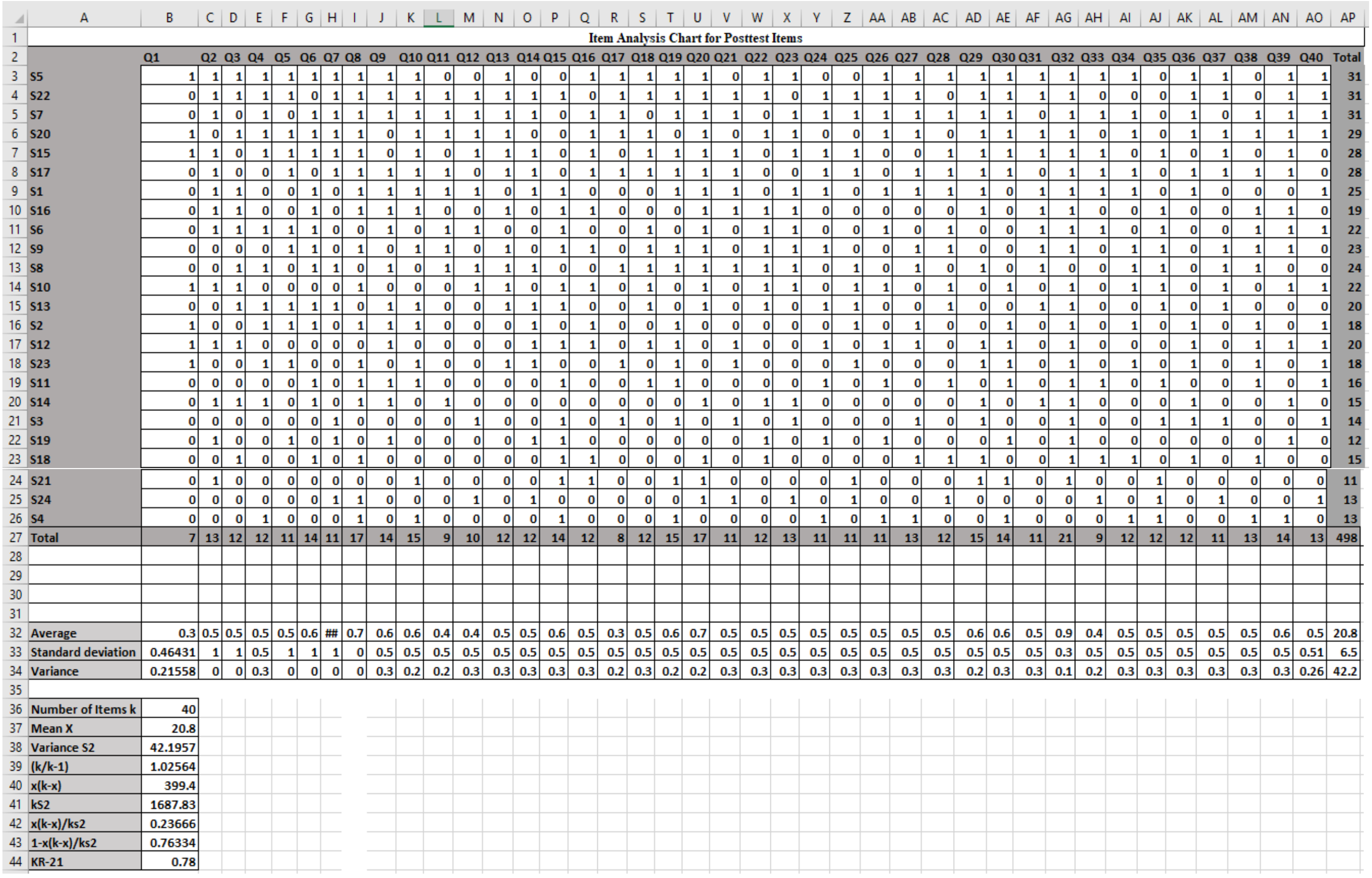
Remarks:1
D ≥ 0.40 = Very Good Item = Retain
0.30 ≤ D ≤ 0.39 = Fair quality = Usable Item
0.20 ≤ D ≤ 0.29 = Marginal Item = Revise
D ≤ 19 = Poor Item = Revise or Discard

Remarks: 2
0.75 ≤ p ≤ 1.0 = Easy = Revise or Discard
0.26 ≤ p ≤ 0.74 = Average = Retain
p ≤ 0.25 = Hard = Revise or Discard

Source: Adapted from Obon and Rey (2019)

Note:
1. if both the value lies out of the ranges, then the item was discard
2. If any one value lies out of the specified ranges, then the item was revised

Appendix V: Reliability Test for Posttest Items



Item Analysis Chart for Posttest Items

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32	Q33	Q34	Q35	Q36	Q37	Q38	Q39	Q40	Total
S5	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	31
S22	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	0	0	1	1	0	1	1	31
S7	0	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	1	31
S20	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	0	1	0	1	1	0	0	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	29
S15	1	1	0	1	1	1	1	1	0	1	0	1	1	1	0	1	0	1	1	1	1	0	1	1	1	0	0	1	1	1	1	1	1	0	1	0	1	0	1	0	28
S17	0	1	0	0	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1	0	28
S1	0	1	1	0	0	1	0	1	1	1	1	1	0	1	1	0	0	0	1	1	1	0	1	1	0	1	1	1	1	0	1	1	1	1	0	1	0	0	0	1	25
S16	0	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	0	0	0	1	1	1	1	0	0	0	0	0	1	0	1	1	0	0	1	0	0	1	1	0	19
S6	0	1	1	1	1	1	0	0	1	0	1	1	0	0	1	0	0	1	0	1	0	1	1	0	0	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	22
S9	0	0	0	0	1	1	0	1	0	1	1	0	1	0	1	1	0	1	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1	1	0	1	1	1	0	23
S8	0	0	1	1	0	1	1	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	0	1	0	1	0	1	0	0	1	1	0	1	1	0	0	24
S10	1	1	1	0	0	0	0	1	0	0	0	1	1	0	1	1	0	1	0	1	0	1	1	0	1	1	0	1	0	1	0	1	0	1	1	0	1	0	1	1	22
S13	0	0	1	1	1	1	1	0	1	1	0	0	1	1	1	0	0	1	0	1	0	1	0	1	1	0	0	1	0	0	1	1	0	0	1	0	1	0	0	0	20
S2	1	0	0	1	1	1	0	1	1	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	1	0	1	0	1	0	1	0	1	18
S12	1	1	1	0	0	0	0	0	1	0	0	0	0	1	1	1	0	1	1	0	1	0	0	1	0	1	1	0	1	1	0	1	0	0	0	1	0	1	1	1	20
S23	1	0	0	1	1	0	0	1	0	1	0	0	1	1	0	0	1	0	1	0	1	0	0	0	1	0	0	0	1	1	0	1	0	1	0	1	0	1	0	1	18
S11	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	0	0	1	1	0	0	0	0	1	0	1	0	1	0	1	0	1	1	0	1	0	0	1	0	1	16
S14	0	1	1	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	1	0	15
S3	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	1	0	0	1	0	0	1	1	1	0	0	1	14
S19	0	1	0	0	1	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	12
S18	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	0	1	0	1	0	0	15
S21	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	1	1	0	0	0	0	1	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	11
S24	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	0	1	0	1	0	1	0	0	1	13
S4	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	1	1	0	0	1	0	0	0	1	1	0	0	1	1	0	13
Total	7	13	12	12	11	14	11	17	14	15	9	10	12	12	14	12	8	12	15	17	11	12	13	11	11	11	13	12	15	14	11	21	9	12	12	12	11	13	14	13	498
Average	0.3	0.5	0.5	0.5	0.5	0.6	##	0.7	0.6	0.6	0.4	0.4	0.5	0.5	0.6	0.5	0.3	0.5	0.6	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.9	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.5	20.8
Standard deviation	0.46431	1	1	0.5	1	1	1	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.51	6.5
Variance	0.21558	0	0	0.3	0	0	0	0	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.26	42.2

Number of Items k	40
Mean X	20.8
Variance S2	42.1957
(k/k-1)	1.02564
x(k-x)	399.4
kS2	1687.83
x(k-x)/ks2	0.23666
1-x(k-x)/ks2	0.76334
KR-21	0.78

Appendix VI: Attitude Test Towards Physics Education

Attitude Towards Physics Education Checklist

Items	SA	A	N	D	SD
Factor I: Enthusiasm toward Physics Education					
1. I appreciate learning about physical occurrences and their descriptions the most.					
2. It is not worthwhile to study physics issues in more detail.					
3. Performing a physics experiment in a lab boosts my confidence.					
4. Everyone benefits from having a foundational understanding of physics.					
5. I find studying physics to be tedious.					
6. I'm motivated to conduct additional experiments after a successful physics experiment.					
7. I'd be pleased to have fewer practical physics work so that I may spend more time studying theory.					
8. I finish my physics assignments on time.					
9. I look forward to physics class with anticipation.					
10. With my friends, I discuss about physics.					
Factor II: Physics Education learning					
1. In regards to my responses to the physics class questions, I am really happy and satisfied.					
2. Physics laboratory work increases individual productivity.					
3. I continue to practice the class problems until I master them.					
4. In my physics lesson, I feel under pressure.					
5. Understanding of physics is effectively achieved when students actively participate in both theory and practical lessons.					
6. Problem with real-world situation due to lack of physics courses					

7. I make an effort to relate the physics issue to real-world circumstances.					
8. Instead of tackling physics problems, I try to concentrate more on memorizing the laws and derivations from the textbook.					
9. Numerous physics scenarios are challenging to visualize.					
10. It is exceedingly challenging to pass a physics exam without using a cheat sheet.					
11. I am not interested in challenging physics topics.					
12. I'm forced to study physics by my parents and my teacher.					
13. I only study physics when it's time for an exam.					
14. It's beyond my capacity to learn physics.					
Factor III: Physics as a process					
1. Physics is a subject that is always changing					
2. Physics is a process for acquiring knowledge, not just a body of knowledge					
3. The laws that have already been discovered do not require further verification					
4. The truth of the laws of physics might no longer hold true tomorrow due to the rapid advancement of scientific knowledge					
5. There will eventually be a discovery of all physics laws					
6. In order to improve civilization and society, physics is crucial					
7. Physics is all about memorization of rules and formulas; it lacks creativity					
8. Science and other subjects have benefited immensely from the study of physics					
9. Physics trains the mind and fosters critical thinking in students					

10. Building a physics laboratory requires a substantial amount of infrastructure in order to comprehend the field					
Factor IV: Physics teacher					
1. My physics teacher makes me nervous					
2. My physics teacher consistently gives the students too many assignments					
3. Problem-solving is encouraged by my physics teacher					
4. The numerical problems regarding with a physics topic covered in class are rarely discussed by my physics teacher					
5. My physics teacher regularly attends class every time					
6. My physics teacher discourages students from addressing questions in class					
7. My physics teacher doesn't explain the material in the lesson in a coherent manner					
8. During class, my physics teacher employs a variety of teaching strategies					
9. My physics teacher frequently conducts lessons in a lecture format					
10. My physics teacher takes the necessary time to explain physics concepts to me					
11. My physics teacher doesn't think I can learn					
12. My physics teacher often loses patience with me					
13. My physics teacher places a strong emphasis on comprehension rather than rote learning					
14. In the future, I want to be a physics teacher					
Factor V: Physics as a future vocation					
1. Being a physicist involves very little professional progression					
2. Studying physics requires a lot of tolerance and patience					
3. A physicist's progress is relatively slow					
4. Jobs opportunities in physics are scarce					

5. A very committed person working to better society is a physicist					
6. There is a lack of creativity in the field of physics					
7. A physicist spends their entire life doing experiments					
8. Higher-level physics study leads to a bright future					
9. Since none of their research has any applicability in the real world, physicists waste public money					
10. In general, physicists are socially isolated					

Note. Adapted from the paper of Kaur and Zhao (2017).

Appendix VII: Relationship among variables in the study

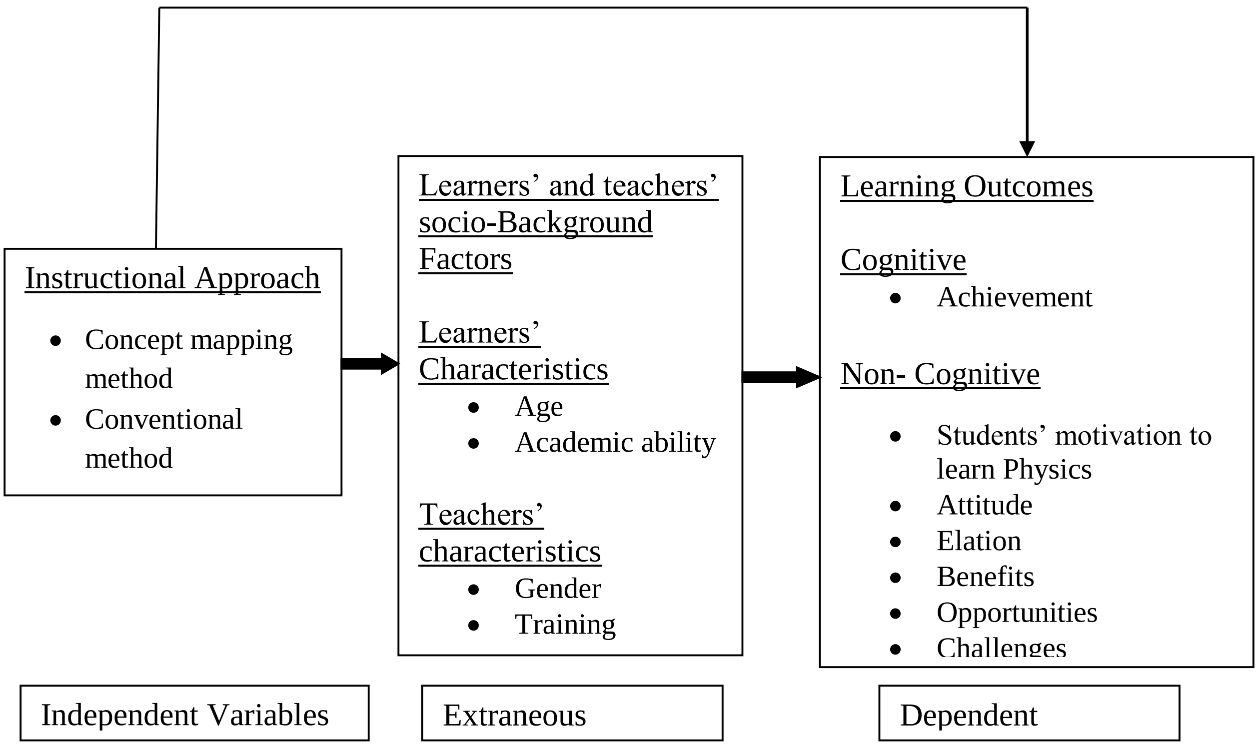


Fig: Relation between variables in research.

Appendix VIII: Physics Achievement Test (PAT) Paper

Physics Achievement Test (PAT) Paper for Pre-Test

Item Question – I

Time: 45 minutes

F.M.: 40

Instructions: **Read the following questions carefully and choose the correct answer that best describes the answer. Write your answer in a separate answer sheet.**

1. SI unit of charge is
   - a) volt
   - b) ampere
   - c) coulomb
   - d) coulomb/sec

2. The charge distributed per unit surface area is called
   - a) surface charge density
   - b) volume charge density
   - c) linear charge density
   - d) current density

3. The unit of electric field intensity is
   - a) Coulomb
   - b) coulomb/m^2
   - c) Weber
   - d) newton/coulomb

4. Gauss's law is valid for
   - a) any closed surface
   - b) only regular close surfaces
   - c) any open surface
   - d) only irregular open surfaces

5. The electric field by the infinite plane sheet of charge will be
   - a) $\frac{\sigma}{\varepsilon_0}$
   - b) $\frac{\sigma}{3\varepsilon_0}$
   - c) $\frac{\sigma}{2\varepsilon_0}$
   - d) $\frac{\sigma}{4\varepsilon_0}$

6. How many conductors does the capacitor consist of?
   - a) One
   - b) Two

c) Three d) Four

7. The capacitance of 1 μF equals
   a) 10^{-12}F b) 10^{-8}F
   c) 10^{-6}F d) 10^{-4}F

8. Dielectrics are
   a) insulating materials b) semiconducting materials
   c) magnetic materials d) conducting materials

9. An instrument which detects electric current in the circuit is known as
   a) voltmeter b) wattmeter
   c) ohmmeter d) galvanometer

10. The SI unit of current density is
    a) $\mathrm{N/m^2}$ b) $\mathrm{A/m^2}$
    c) $\mathrm{Nm^2}$ d) $\mathrm{J/m^2}$

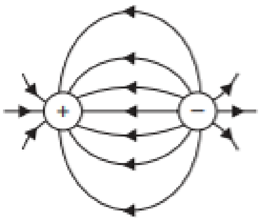
Group B

11. When a glass rod is rubbed with silk, it
    a) gains electrons from silk b) gives positive charge to silk
    c) gains positive charge from silk d) gives protons to silk

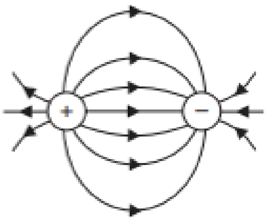
12. The law, governing the force between electric charges is known as
    a) Ampere’s law b) Ohm’s law
    c) Faraday’s law d) Coulomb’s law

13. A positive charge and a negative charge of equal magnitude are placed at a short distance apart. Which diagram best represents the associated electric field?

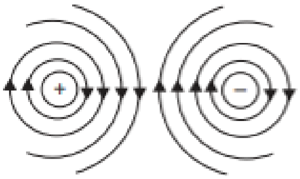
a)



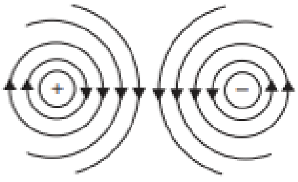
b)



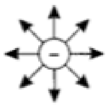
c)



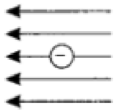
d)



14. Which of the following figures represent the electric field lines due to a single negative charge?



a)



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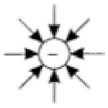
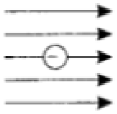


c)



d)

15. Total electric flux coming out of a unit positive charge kept in air is
    - a) ε_0
    - b) ${\varepsilon_0}^{-1}$
    - c) $(4\pi\varepsilon_0)^{-1}$
    - d) $4\pi\varepsilon_0$

16. If a dielectric is inserted between the parallel plate capacitor, then capacitance will
    - a) remains the same
    - b) increases
    - c) decrease
    - d) increase initially and then decrease

17. Which one of the following remains the same during the series combination of capacitors?
    - a) Voltage
    - b) Charge
    - c) Capacitance
    - d) Resistance

18. The capacitance between two plates increases with
    a) smaller plate area and higher applied voltage
    b) smaller plate area and smaller distance between them
    c) larger plate area and distance between plates and higher applied voltage
    d) larger plate area and smaller distance between plates

19. With rise in temperature the resistance of pure metals
    a) increases b) decreases
    c) first increases and then decreases d) remains constant

20. A moving coil galvanometer can be converted into an ammeter by connecting to the moving coil galvanometer
    a) a low resistance in series b) a low resistance in parallel
    c) a high resistance in parallel d) a high resistance in series

Group C

21. A positively charged rod is brought near an uncharged conductor. If the rod is then suddenly withdrawn, the charge left on the conductor will be
    a) Positive b) negative
    c) Zero d) more positive than negative

22. The force experienced by q charge in an electric field intensity E is given by
    a) $F = \frac{q}{m}$ b) $F = mg$
    c) $F = qE$ d) $F = q/A$

23. If the distance between two charges is halved, what will happen the force between the charges?
    a) $\mathrm{F}' = 4\mathrm{F}$ b) $\mathrm{F}' = 2\mathrm{F}$
    c) $\mathrm{F}' = \mathrm{F}$ d) $\mathrm{F}' = \mathrm{F}/2$

24. Two conducting spheres of radii r_1 and r_2 are given the same potential. The ratio of their charges will be

a) $\frac{r_1}{r_2}$ b) $\sqrt{\frac{r_1}{r_2}}$ c) $\frac{r_1}{1+r_2}$ d) $\frac{r_2}{1+r_1}$

25. What is the conduction current when a capacitor is fully charged?

a) Infinity b) Zero

c) Equal to 1 d) Less than 1

26. Two capacitors, each of capacity 2 µF, are connected in parallel. This system is connected in series with a third capacitor of 12 µ F capacity. The equivalent capacity of the system will be

a) 16 µF b) 13 µF

c) 4 µF d) 3 µF

27. What is the area of the plates of a 3 F parallel plate capacitor, if the separation between the plates is 5 mm?

a) $1.7 \times 10^9 m^2$ b) $4.5 \times 10^9 m^2$

c) $9.3 \times 10^9 m^2$ d) $12.9 \times 10^9 m^2$

28. The energy stored in a parallel plate capacitor with air between its plates is U. If air is replaced by glass (dielectric constant = 5) between the plates, the energy stored in it will be

a) 5U b) $\frac{U}{5}$

c) 10U d) $\frac{U}{10}$

29. If the length of a resistance wire is doubled and its cross-sectional area is halved, then the resistivity would

a) increase two times b) increase four times

c) increase eight times d) remain unchanged

30. What is the resistance of the resistor in this circuit?

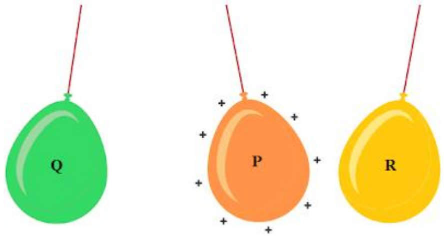
a) 10 Ω b) 20 Ω

c) 30 Ω d) 40 Ω

Group D

31. Two balloons, Q and R, are charged and placed either side of balloon P. The balloons move to the positions shown in Figure. Which row of the table is correct for the charge on balloons Q and R.?

	Sign of charge on Q	Sign of charge on R
a)	Negative	Negative
b)	Negative	Positive
c)	Positive	Negative
d)	Positive	Positive

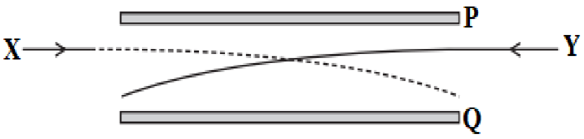


32. There is a potential difference between a pair of parallel plates. Which values of potential difference and separation of the plates will produce an electric field strength of the greatest value?

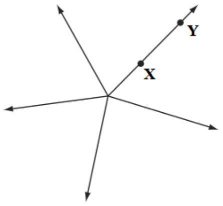
	Potential difference	Separation
a)	2V	2d
b)	2V	$\frac{d}{2}$
c)	$\frac{V}{2}$	2d
d)	$\frac{V}{2}$	$\frac{d}{2}$

33. The diagram shows the paths of two charged particles, X and Y, during their passage between a pair of oppositely charged metal plates, P and Q. The plates are charged such that the electric field between them is directed from Q to P. Which charges on X and Y will produce the observed paths?

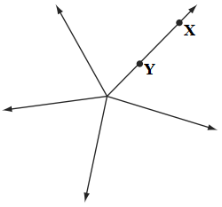
	X	Y
a)	-	-
b)	-	+
c)	+	-
d)	+	+



34. In each electric field diagram, a positively charged particle is moved from X to Y. In which diagram would the particle experience an increasing repulsive force?



a)



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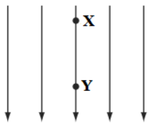

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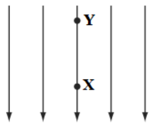


d)

35. The ratio of the radius of two spherical conductors is 1: 2 then the ratio of their capacitance will be

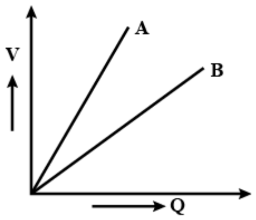
a) 4:1

b) 1: 4

c) 1: 2

d) 2: 1

36. The given graph shows the variation of charge Q versus potential difference V for two capacitors C_A and C_B. The two capacitors have same plate separation but the plate area of C_B is double than that of C_A. Which of the following relationship between two capacitances?



a) $C_A = C_B$

b) $C_A < C_B$

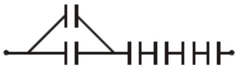
c) $C_A > C_B$

d) $C_A \cong C_B$

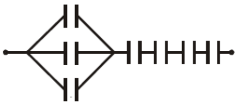
37. Seven capacitors, each of capacitance 2μF, are to be connected in a configuration to obtain an effective capacitance of 6/13 μF. Which of the combinations, shown in figures below, will achieve the desired value?

a)

b)



c)



d)

38. In the equation AB = C, A is an electric current, C is the voltage, then B is

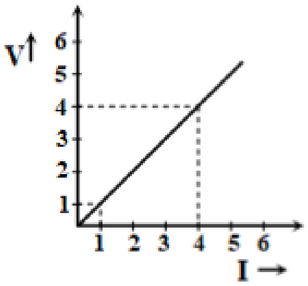
a) area

b) length

c) resistance

d) potential difference

39. Variation of current and voltage in a conductor has been shown in the diagram below. The resistance of the conductor is



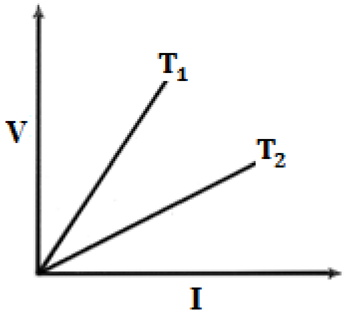
a) 4 ohm

b) 2 ohm

c) 3 ohm

d) 1 ohm

40. The current in a metallic conductor is plotted against voltage at two different temperatures T_1 and T_2. Which one of the following is the correct relation between T_1 and T_2?



a) $T_1 > T_2$

b) $T_1 < T_2$

c) $T_1 = T_2$

d) $T_1 \le T_2$

Appendix IX: Physics Achievement Test (PAT) Paper

Physics Achievement Test (PAT) Paper for Post-Test

Item Question – II

Time: 45 minutes

F.M.: 40

Instructions: **Read the following questions carefully and choose the correct answer that best describes the answer. Write your answer in a separate answer sheet.**

Group A

1. Charge on electron, a fundamental charged particle, is equal to
   a) $9.1 \times 10^{-19} C$ b) $6.1 \times 10^{-19} C$
   c) $1.6 \times 10^{-19} C$ d) $1.9 \times 10^{-19} C$

2. The charge density at a point on the surface of radius r is
   a) inversely proportional to area b) directly proportional to area
   c) inversely proportional to r^2 d) directly proportional to r^2

3. The force per unit charge is known as
   a) electric flux b) electric field
   c) electric potential d) electric current

4. Gauss's law is true only if force due to a charge varies as
   a) r^{-1} b) r^{-2}
   c) r^{-3} d) r^{-4}

5. The electric field due to an infinitely long straight uniformly charged wire at a distance r is directly proportional to
   b) r b) r^2
   c) r^{-1} d) r^{-2}

6. A capacitor consists of two
   a) insulation separated by a dielectric
   b) conductors separated by an insulator
   c) ceramic plate and one mica disc
   d) silver-coated insulators

7. 1000 pF is equal to
   a) 1 nF b) 0.9 nF
   c) 0.10 nF d) 0.8 nF

8. In which type of dielectric molecules, the center of gravity of positive and negative charges coincides with each other?
   a) Polar b) Unipolar
   c) Non-polar d) Bipolar

9. Which of the following instrument is used for measuring electrical resistance?
   a) ohmmeter b) voltmeter
   c) ammeter d) galvanometer

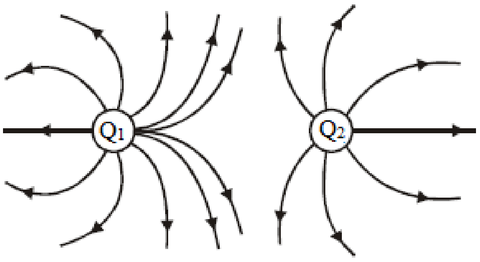
10. SI unit of the conductivity of the material is
    a) Ωm b) Ω
    c) $\Omega^{-1}\text{m}$ d) $\Omega^{-1}\text{m}^{-1}$

Group B

11. When a plastic rod is rubbed with wool, it
    a) gains electrons from wool b) gives electrons to wool
    c) gives positive charge from wools d) gives protons to wools

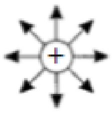
12. The force due to Coulomb's law between two charges is
    a) directly proportional to distance between them.
    b) directly proportional to square of distance between them
    c) inversely proportional to distance between them
    d) inversely proportional to square of distance between them

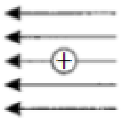
13. Which one of following is the correct information about electric lines of forces due to charges Q_1 and Q_2?

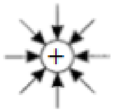


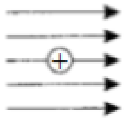
a) Q_1 and Q_2 both are negative
b) Q_1 and Q_2 both are positive
c) Q_1 is greater than Q_2
d) Q_1 is less than Q_2

14. Which of the following figures represent the electric field lines due to a single positive charge?


a)


b)


c)


d)

15. If ϕ is electric flux through a closed surface ‘S’, ‘q’ is total charge enclosed by ‘S’ and ε_0 is the permittivity of free space, then these three are related by Gauss’ law formula by

a) $\phi = q\varepsilon_0$
b) $\phi = \frac{q}{\varepsilon_0}$
c) $\phi = \frac{\varepsilon_0}{q}$
d) $\phi = \sqrt{(q\varepsilon_0)}$

16. When a dielectric is placed in an electric field, the field strength

a) increases
b) decrease
c) remain unchanged
d) reduces to zero

17. Which one of the following varies during the series combination of capacitors?

b) Voltage
b) Charge
c) Capacitance
d) Resistance

18. In a parallel plate capacitor, the capacitance increases if
    a) area of the plate is decreased
    b) distance between the plates increases
    c) area of the plate is increased
    d) dielectric constant decreases

19. With rise in temperature the conductance of pure metals
    a) increases b) decreases
    c) first increases and then decreases d) remains constant

20. A galvanometer acting as a volt-meter will have with its coil
    a) a high resistance in parallel b) a high resistance in series
    c) a low resistance in parallel d) a low resistance in series

Group C

21. A negatively charged rod is brought near an uncharged conductor. If the rod is then suddenly withdrawn, the charge left on the conductor will be
    a) Positive b) Negative
    c) Zero d) more negative than positive

22. The magnitude of electric field intensity E is such that, an electron placed in it would experience an electrical force equal to its weight is given by
    a) mge b) mg/e
    c) e/mg d) $\frac{e^2g}{m^2}$

23. Two charges of equal magnitudes kept at a distance r exert a force F on each other. If the charges are halved and distance between them is doubled, then the new force acting on each charge is
    a) $\frac{F}{8}$ b) $\frac{F}{4}$
    c) 4F d) $\frac{F}{16}$

24. Two conducting spheres of radii r_1 and r_2 are given the same charge. The ratio of their potentials will be

    b) $\frac{r_2}{r_1}$ b) $\sqrt{\frac{r_1}{r_2}}$ c) $\frac{r_1}{1+r_2}$ d) $\frac{r_2}{1+r_1}$

25. When will be capacitors fully charged?
    a) When voltage is zero
    b) When the supply voltage is equal to the capacitor voltage
    c) When voltage is infinity
    d) When capacitor voltage is equal to half the supply voltage

26. Two capacitors, each of capacity 2 μF, are connected in series. This system is connected in parallel with a third capacitor of 12 μ F capacity. The equivalent capacity of the system will be
    a) 16 μF b) 13 μF
    c) 4 μF d) 3 μF

27. What is the distance of separation between the plates of a 3 F air filled parallel plate capacitor, if the area of each plate is $1.7 \times 10^9 m^2$?
    a) $5 \times 10^{-3} m$ b) $15 \times 10^{-3} m$
    c) $5.5 \times 10^{-3} m$ d) $12.9 \times 10^{-3} m$

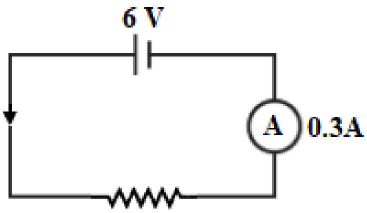
28. By inserting a plate of dielectric material between the plates of a parallel plate capacitor, the energy is decreased five times. The dielectric constant of the material is
    a) $\frac{1}{25}$ b) $\frac{1}{5}$
    c) 5 d) 25

29. When the length of the conductor is doubled and the area of cross-section remains the same then its resistance
    a) remains the same b) will be doubled
    c) will become half d) will increase by four times

30. If the resistance in the following circuit is halved, what will current be?

a) 0.2 A b) 0.4 A

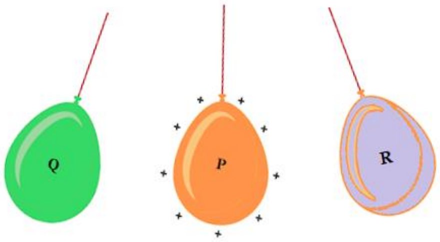
c) 0.6 A d) 0.8 A



Group D

31. Two balloons, Q and R, are charged and placed either side of balloon P. The balloons move to the positions shown in Figure. Which row of the table is correct for the charge on balloons Q and R.?

	Sign of charge on Q	Sign of charge on R
a)	Negative	Negative
b)	Negative	Positive
c)	Positive	Negative
d)	Positive	Positive

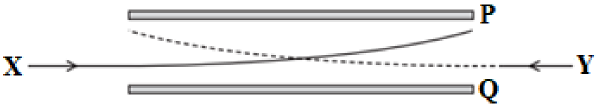


32. There is a potential difference between a pair of parallel plates. Which values of potential difference and separation of the plates will produce an electric field strength of the least value?

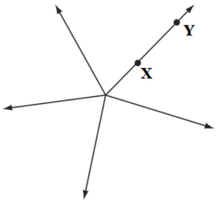
	Potential Difference	Separation
a)	2V	2d
b)	2V	$\frac{d}{2}$
c)	$\frac{V}{2}$	2d
d)	$\frac{V}{2}$	$\frac{d}{2}$

33. The diagram shows the paths of two charged particles, X and Y, during their passage between a pair of oppositely charged metal plates, P and Q. The plates are charged such that the electric field between them is directed from Q to P. Which charges on X and Y will produce the observed paths?

	X	Y
a)	-	-
b)	-	+
c)	+	-
d)	+	+



34. In each electric field diagram, a negatively charged particle is moved from X to Y. In which diagram would the particle experience an increasing attractive force?



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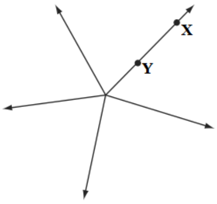

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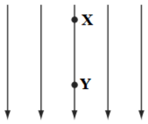
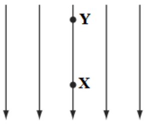


c)



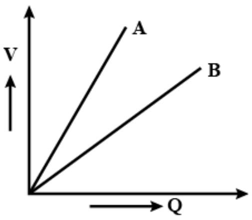
d)

35. Two metal spheres of capacitance, C_1 and C_2 carry some charges. They are put in contact and then separated. The final charges Q_1 and Q_2 on them will satisfy

a) $\frac{Q_1}{Q_2} < \frac{C_1}{C_2}$ b) $\frac{Q_1}{Q_2} = \frac{C_1}{C_2}$

c) $\frac{Q_1}{Q_2} > \frac{C_2}{C_1}$ d) $\frac{Q_1}{Q_2} = \frac{C_2}{C_1}$

36. The graph shows the variation of voltage 'V' across the plates of two capacitors A and B versus increase of charge 'Q' stored on them. Which of the following relationship between two capacitances?



a) $C_A = C_B$ b) $C_A < C_B$

c) $C_A > C_B$ d) $C_A \cong C_B$

37. Seven capacitors each of capacitance 2 μF are to be connected to obtain a capacitance of 10/11 μF. Which of the following combination is possible?

a) 5 in parallel, 2 in series b) 4 in parallel, 3 in series

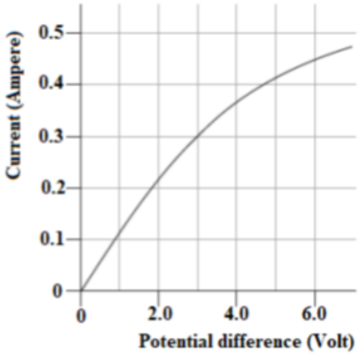
c) 3 in parallel, 4 in series d) 2 in parallel, 5 in series

38. In the equation AB = C, A is the current density, C is the electric current, then B is

a) area b) length

c) resistance d) potential difference

39. The graph shows the variation of current with potential difference (voltage) for filament lamp. From graph, compute the resistance of the lamp when the current in the lamp is 0.3 A.



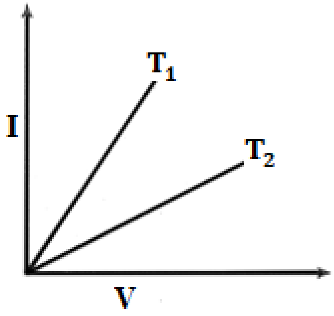
a) 10 ohms

b) 20 ohms

c) 30 ohms

d) 40 ohms

40. The current in a metallic conductor is plotted against voltage at two different temperatures T_1 and T_2. Which one of the following is the correct relation between T_1 and T_2?



a) $T_1 > T_2$

b) $T_1 < T_2$

c) $T_1 = T_2$

d) $T_1 \leq T_2$

Appendix X: Answer Sheet for Achievement Test Paper

Answer Key for Pre-Test

Q.N.	Group A	Q.N.	Group B	Q.N.	Group C	Q.N.	Group D
1.	c	11.	c	21.	c	31.	c
2.	a	12.	d	22.	c	32.	b
3.	d	13.	b	23.	a	33.	a
4.	a	14.	a	24.	a	34.	b
5.	c	15.	b	25.	b	35.	c
6.	b	16.	b	26.	d	36.	c
7.	c	17.	b	27.	a	37.	d
8.	a	18.	d	28.	b	38.	c
9.	d	19.	a	29.	d	39.	d
10.	b	20.	b	30.	b	40.	a

Appendix XI: Answer Sheet for Achievement Test Paper

Answer Key for Post Test

Q.N.	Group A	Q.N.	Group B	Q.N.	Group C	Q.N.	Group D
1.	c	11.	a	21.	c	31.	d
2.	c	12.	d	22.	b	32.	c
3.	b	13.	b	23.	d	33.	d
4.	b	14.	a	24.	a	34.	b
5.	c	15.	b	25.	b	35.	b
6.	b	16.	b	26.	b	36.	c
7.	a	17.	a	27.	a	37.	a
8.	c	18.	c	28.	c	38.	a
9.	a	19.	b	29.	b	39.	a
10.	d	20.	b	30.	c	40.	b

Appendix XII: Answer Sheet for Achievement Test Paper

Answer Sheet

Name of Student:	Age:	Gender:
Roll No.:	Academic Batch:	Class:
Name of School:	Address:	Caste:

***Instructions*: Read the given questions carefully and write the correct option that best describes the answer.**

Q.N.	Group A	Q.N.	Group B	Q.N.	Group C	Q.N.	Group D
1.		11.		21.		31.	
2.		12.		22.		32.	
3.		13.		23.		33.	
4.		14.		24.		34.	
5.		15.		25.		35.	
6.		16.		26.		36.	
7.		17.		27.		37.	
8.		18.		28.		38.	
9.		19.		29.		39.	
10.		20.		30.		40.	

Appendix XIII: Contents of Electrostatics and Direct Current Circuit in B.Ed. Second year (As prescribed by FOE)

Course title: **Physics II**	Full marks : 100 (80T + 20P)
Course No. : Sc. Ed. 422	Pass marks : 28T + 8P
Nature of the Course: Theory & Practical	Periods per week: 9 (6T + 3P) ,
Level : B.Ed. (4 Year)	Practical (3P) : 3pds/day/Week/gr.
Year: Second	Total Periods: 150
	Time per period : 55 minutes

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1. Course Description

This course aims to develop advanced knowledge in Physics. It is divided into two parts: theory and practical. The first part deals with concepts, principles and laws. It includes Waves and Oscillation, Sound waves and Physical optics. The theory part also focuses on Electrostatics, Current Electricity and The Universe. The second part deals with practical activities related to Wave and Sound, Physical Optics, Electrostatics, Current Electricity and the Universe.

The students are required to secure pass marks in theory as well as practical courses separately.

1. General Objectives

The general objectives of the course are as follows:

a. To acquaint the students with the basic properties of Wave motion and Sound waves.

b. To make the students familiar with the theoretical aspects of Electrostatics and Current Electricity.

c. To provide in-depth knowledge about the different phenomena related to Physical Optics and the Universe.

2. Specific Objectives and Contents

Part I: Theory

Specific Objectives	**Contents**
• Discuss some process of electrification. • Describe quantization of electric charge. • Explain Modern theory of electrification. • Define electrostatic induction. • Explain the process of charging by electrostatic induction. • Describe Faraday's Ice pail experiment. • Define and explain the term surface charge density. • Discuss action of points. • Describe van de Graff generator.	**Units VIII: Fundamentals of Electrostatics (5)** 8.1 Electrification 8.2 Quantization of electric charge 8.3 Modern theory of electrification 8.4 Electrostatic induction 8.5 Charging by electrostatic induction 8.6 Faraday's Ice pail experiment 8.7 Surface charge density 8.8 Action of points 8.9 Van de Graff generator
• State and explain Coulomb's law in electrostatics. • Define relative permittivity in terms of electrostatic force. • Write force between multiple electric charges. • Define electric field.	**Unit IX : Electrostatic Force, Field and Potential (l5)** 9.1 Coulomb's law 9.2 Relative permittivity 9.3 Force between multiple electric charges 9.4 Electric field 9.5 Electric field intensity 9.5.1 Electric field intensity due to a point charge 9.6 Electric flux

• Explain electric field intensity and calculate electric field intensity due to a point charge. • Discuss the term electric flux. • State and explain Gauss's theorem. • Determine the electric field intensity due to a charged sphere by using Gauss's theorem. • Calculate the electric field intensity due to an infinite plane sheet of charge by applying Gauss's theorem. • Calculate the electric field intensity due to a uniform linear charge distribution by applying Gauss's theorem. • Calculate the electric field intensity due to a uniform charged cylinder by applying Gauss's theorem. • Explain electric potential and find it due to a point charge. • Derive an expression of potential difference between two points in electric field. • Define electron volt and calculate its value in terms of joule. • Derive a relation between electric field intensity and potential gradient. • Calculate and expression of potential due to several charges.	9.7 Gauss's theorem 9.8 Applications of Gauss's theorem 9.9 Electric potential due to a point charge 9.10 Potential difference between two points 9.11 Electron volt 9.12 Electric field intensity and potential gradient 9.13 Potential due to several charges

- Solve simple numerical examples related to above topics.	

- Define capacitor and capacitance
- Calculate the capacitance of parallel plate capacitor, co-axial spherical capacitors and co-axial cylindrical capacitor.
- Define permittivity, relative permittivity, dielectric constant and dielectric strength.
- Discuss the effects of dielectric on capacitances, charge and potential difference.
- Classify dielectrics on the basis of molecular structures.
- Explain the dielectric in an electrostatic field and also define polarization.
- Derive an expression of equivalent capacitances in
  - Series combination
  - Parallel combination
- Derive an expression for energy stored in capacitor and energy density.
- Discuss the loss of energy in joining capacitors.
- Explain sharing of charges between two capacitors.
- Describe charging and discharging of a capacitor.
- Discuss the following practical capacitors:
	Unit X: Capacitors (15)
	10.1 Capacitors
	10.2 Capacitance
	10.2.1 Parallel plate capacitor
	10.2.2 Co-axial spherical capacitors
	10.2.3 Co-axial cylindrical capacitors
	10.2.4 Relative permittivity
	10.2.5 Dielectric strength
	10.2.6 Effects of dielectric
	10.3 Classification of dielectrics
	10.3.1 Polar dielectrics
	10.3.2 Non-polar dielectrics
	10.4 Polarization of dielectric
	10.5 Combination of capacitors
	10.6 Energy stored in capacitor and energy density.
	10.7 Loss of energy in joining Capacitors.
	10.8 Sharing of charges between two capacitors.
	10.9 Charging and Discharging of a capacitor.
	10.10 Practical capacitors
	10.10.1 Paper capacitor
	10.10.2 Electrolyte capacitor
	10.10.3 Variable capacitor
	10.9 Lightning
	10.10 Uses of static electric field
	10.10.1 The Electrostatic precipitator

- Paper capacitor - Electrolyte capacitor - Variable capacitor • Explain the process Lightning (In brief) • Discuss the uses of static electric field in following cases: - The Electrostatic precipitator - Xerography • Solve numerical problems on the above given topics.	10.10.2 Xerography
• Define the term DC current, current density, resistance, resistivity, conductance and conductivity. • Define the term temperature coefficient of resistance. • State Ohm's law and verify it experimentally. • Discuss the mechanism of conduction and derive an expression of current relating with drift velocity. • Solve simple numerical examples related to above topics.	**Units XI: Direct current circuit (10)** 11.1 Basic concept 11.1.1 DC current 11.1.2 Current density 11.1.3 Resistance 11.1.4 Resistivity 11.1.5 Conductance 11.1.6 Conductivity 11.2 Temperature coefficient of resistance 11.3 Ohm's law and verification 11.4 Mechanism of conduction. 11.5 Superconductor 11.6 Perfect conductors 11.7 Combination of resistors 11.8 Galvanometer 11.8.1 Shunt 11.8.2 Conversion of galvanometer into an ammeter 11.8.3 Conversion of galvanometer into a voltmeter

	11.9 Ohmmeter 11.10 Potential divider

Appendix XIV: Teaching Episodes for Physics Education in Bachelor Level of Science Education

Episode - One (For Control Group)

Topics: Electrostatic induction

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 563-564
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 87-88 and 91-92.

Learning Outcome:

- Know the ways to electrification of uncharged body.
- Understand the Modern Theory of Electrification.

In class activity (45 min)

Introducing (10*min*)

- Warm up the students about the previous class by asking few questions about
  - Charge
  - Types of charge with examples

Teaching (25*min*)

(5 min)

- Discuss the electrification and write it on the board.

(5 min)

- Tell the students about the ways of electrification and write on the white board as

    - By rubbing
    - By conduction
    - By induction

(5 min)

- Define all the process of electrification by describing and giving lecture note to the students.

(5 min)

- Give an illustration for rubbing process of electrification and explain them.
- Elucidate electrification process to students by rubbing it in our daily lives in the same way that a plastic comb scraped with hair attracts little pieces of paper.
- Explain conduction process as another process of electrification by writing note on the board.
- Describe verbally how the uncharged body becomes charged by electrostatic induction and write it on a white board as a lecture note.

(5 min)

- Explain modern theory of electrification.
- Elucidate the charge produced on neutral atom by rubbing.
- Tell the students about the neutrality breakdown condition while rubbing.

Post-class

Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - What is a charge?
    - How many charges are there?

- Write down the main properties of charge.
- What are the ways of electrification?
- Explain briefly the process of electrification.

Assignment and closure

(5 min)

- Write short note on the process of electrification.
- Describe modern theory of electrification
- Define the term electrostatic induction

Episode - One (For Experimental Group)

Topics: Electrostatic induction

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 563-564
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 87-88 and 91-92.

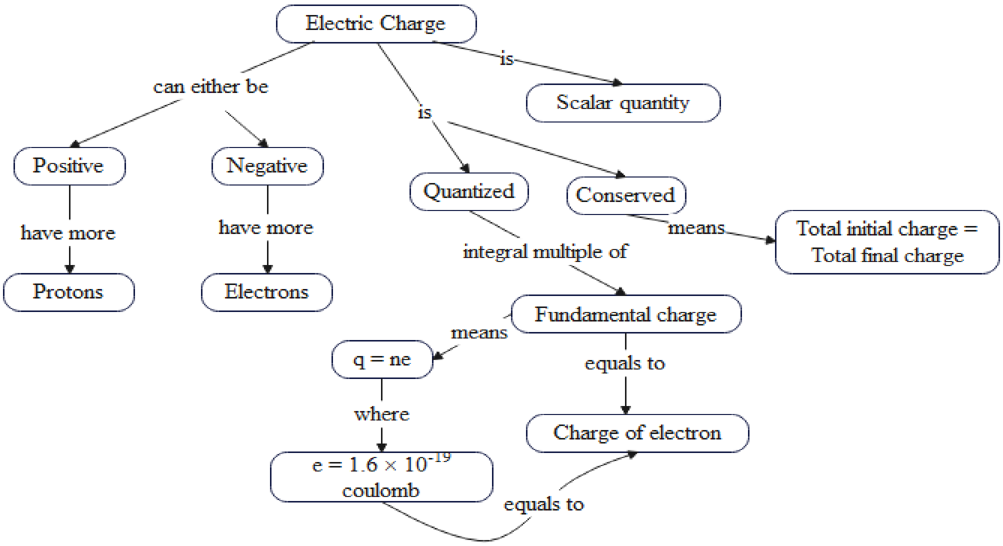
Learning Outcome:

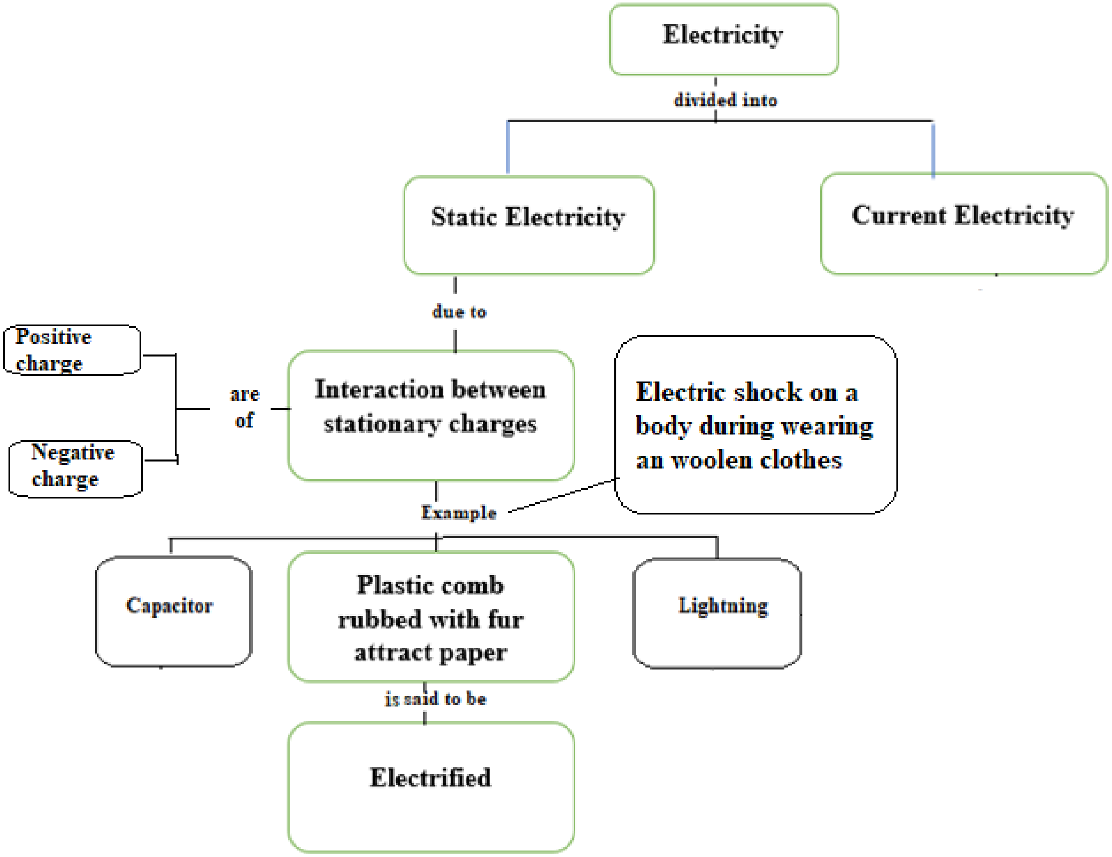
- Know the ways to electrification of uncharged body.
- Understand the Modern Theory of Electrification.

In class activity (45 min)

Introducing (10*min*)

- Warm up the students about the previous class by generating the climate about
    - Charge
    - Types of charge with examples
    - Example of plastic comb rubbed with fur attract small pieces of paper.
    - Example of getting electric shock a lot when we wear woolen clothes.



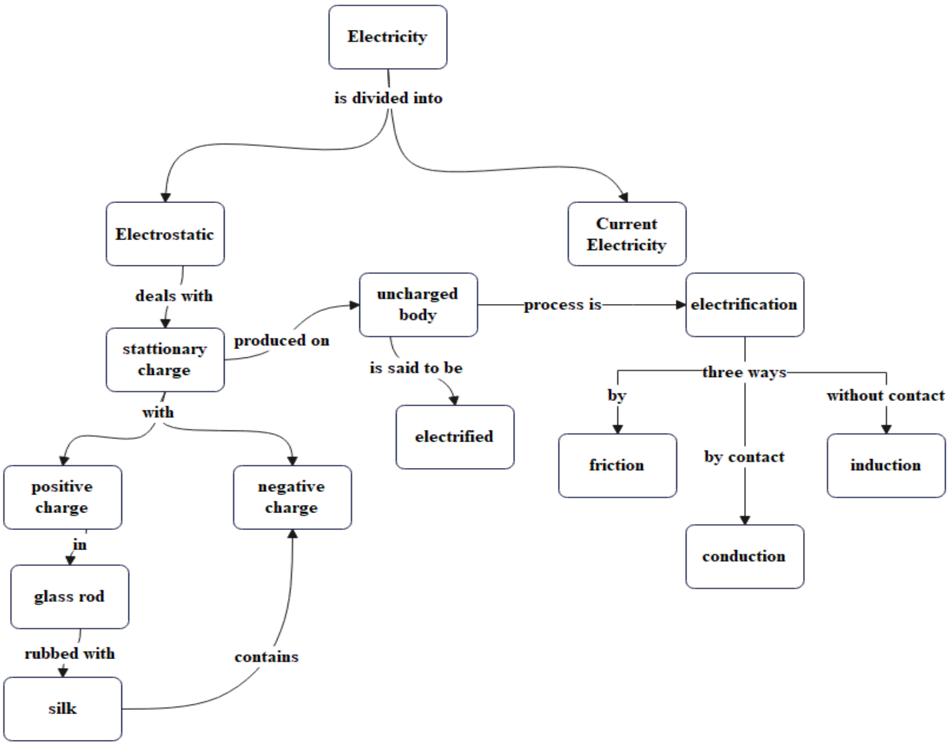


Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

(5 min)

- Present the term electricity and electrification in advance.
- Define the all the terms by drawing concept maps as follows:
- Define the electrification by drawing a concept map on board and elaborate each term by differentiating the main concepts into sub -concepts in hierarchically order.



Phase – II: Presentation of learning Task or Material

(5 min)

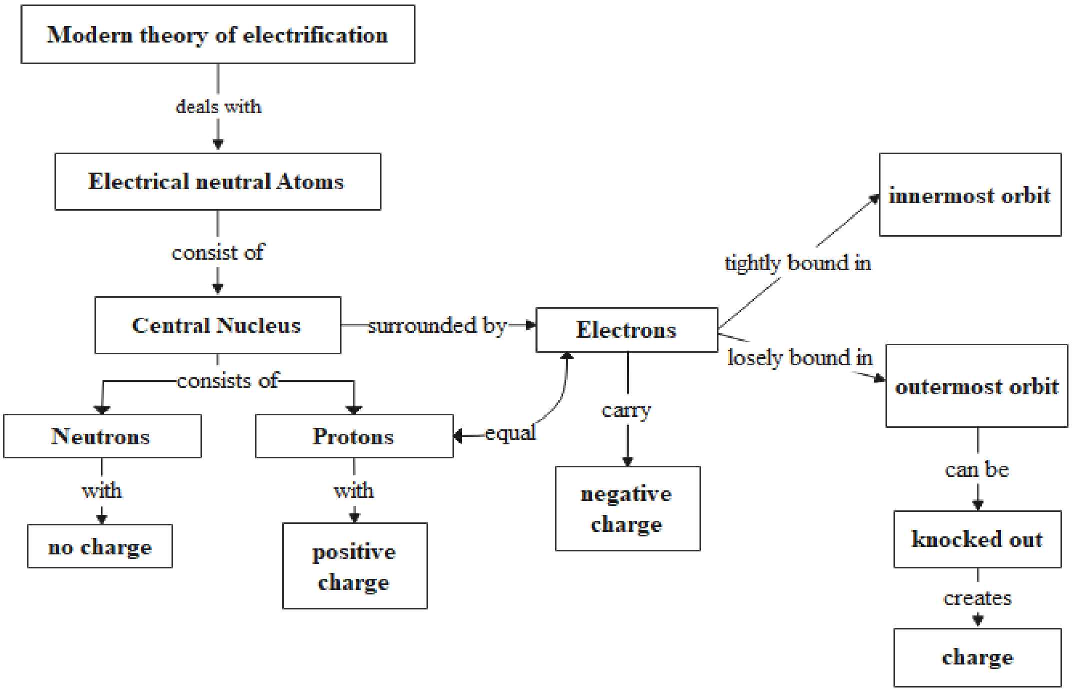
- Explain the students about all concepts like
  - By rubbing
  - By conduction
  - By induction

by showing the same concept map.

- Differentiate all the concepts into sub-concepts in the same concept map that give the information of electrification process by linking with appropriate verb.
- Also, reconcile integration of all sub concepts related with the process of electrification in the same concept map providing with illustrations to get final propositions as:
  - Charges can be produced in uncharged body by friction due to transference of charge between two bodies.
  - Charges can be produced by touching the charged body directly to the uncharged body.
  - Charges can be produced on a uncharged body without touching the charged body directly to the uncharged body.

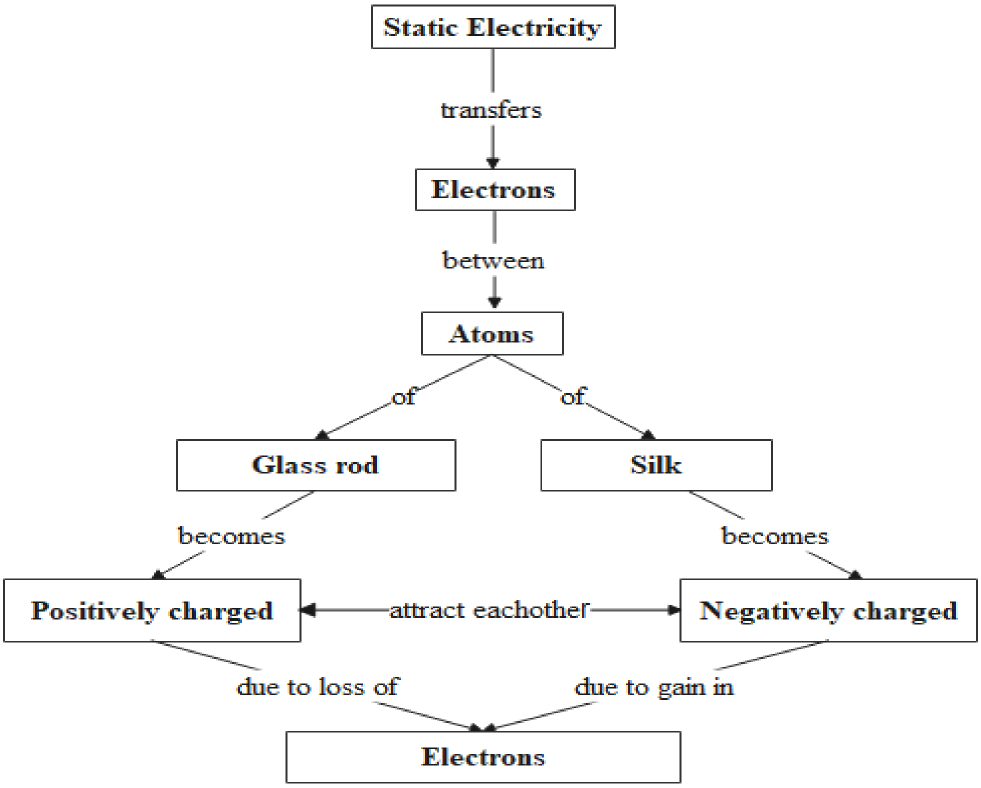
(5 min)

- Explain modern theory of electrification by presenting a concept map related to it.



(5 min)

- Also, elaborate the principle of modern theory of electrification by showing the same concept map.
- In addition, elucidate the concept of electrically neutral atom by presenting same concept map.
- Also, differentiate all the concepts into sub-concepts in the concept map that give the information of the modern theory of electrification by linking with appropriate verbs.
- Describe all sub concepts by showing how neutral atom will get charged on it by electrification process with illustration of glass rod.



(5 min)

- As follows, the reconciliation of merging all sub-concepts was provided by providing relevant examples and hooking them into the main concept to uncover a new proposition as:

- Electrical neutral atom consists of central nucleus.
- Central nucleus is surrounded by electrons.
- Electric neutral atom consists of equal number of protons and electrons.
- Electrons carry negative charge and protons carry positive charge.
- Charge is produced due to the transference of electrons from one body to another by breaking the electrical neutrality of an atom.

Post-class

Phase – III: Strengthening Cognitive organization or Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
  - ➢ Define electrostatics.
  - ➢ What are the ways of electrification?
  - ➢ Explain briefly the process of electrification.

Assignment and closure

(5 min)

- Write short note on the process of electrification.
- Describe modern theory of electrification
- Define the term electrostatic induction

Episode - Two

Topics: Electrostatic Induction

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 563-564
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 87-88 and 91-92.

Learning Outcome:

- Describe modern theory of electrification.
- Understand the principle of electrostatic induction.
- Define the terms involved in process of electrostatic induction.

In class activity (45 min)

Introducing (10*min*)

- Warm up the students about the previous class by asking few questions about
    - ➢ Charge
    - ➢ Types of charge with examples
    - ➢ Modern theory of electrification process
    - ➢ Electrostatic induction

Teaching (25*min*)

Phase - I: Presentation of Advance Organizer

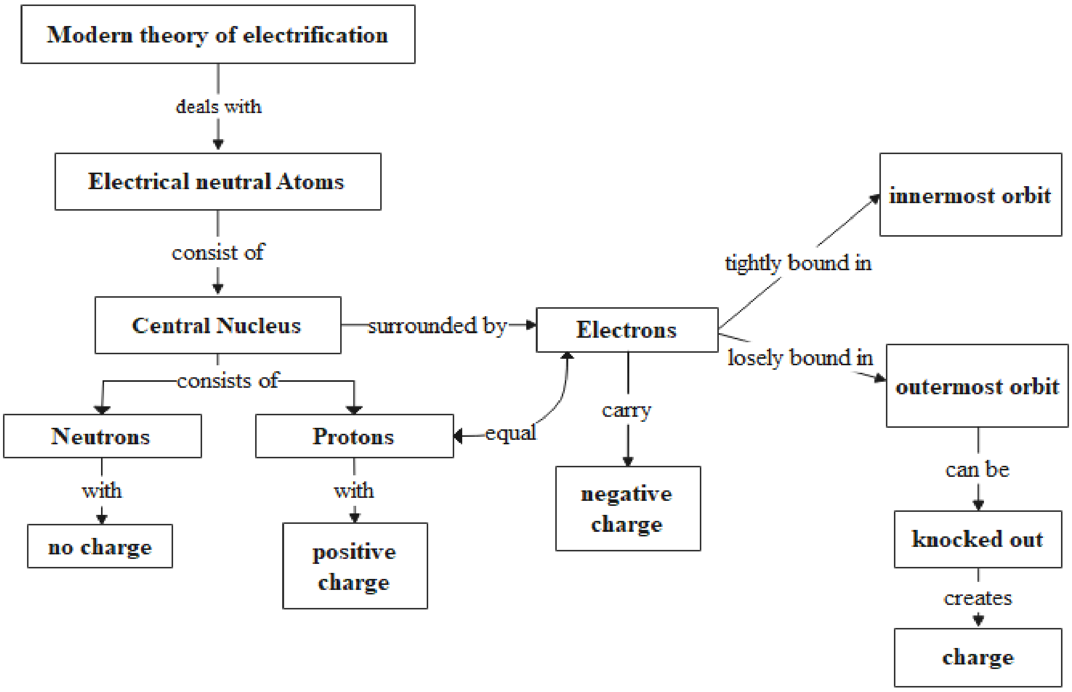
(5 min)

- Present the term electrification as an advance organizer.
- Present the term electrostatic induction as an advance organizer.

Phase - II: Presentation of learning Task or Material

(5 min)

- Define all the process of electrification by presenting concept map relating electrostatic induction.



- Also, elaborate the concept of neutral atom according to modern theory of electrification by showing the same concept map.

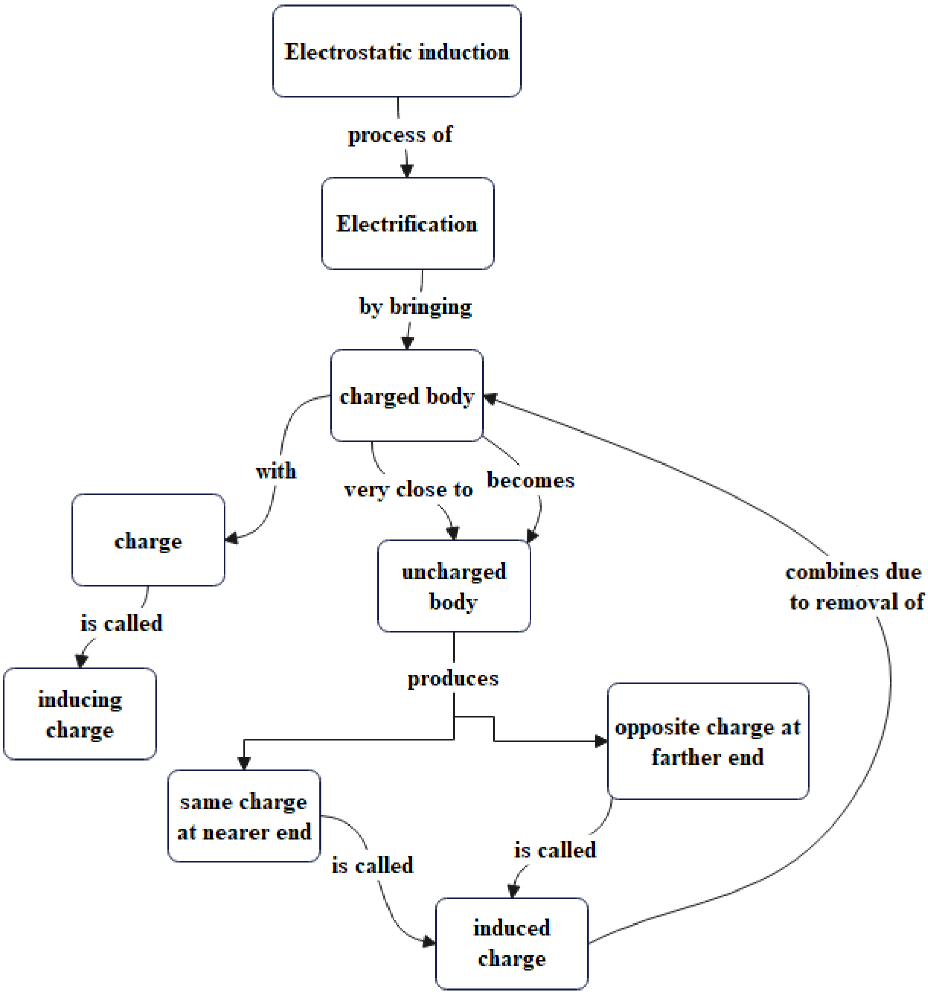
(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electrification by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electrification in the concept map providing with illustrations to get final propositions as:
  - Similar charge repels and dissimilar charge attracts.
  - Electrons revolve around the positive central nucleus.
  - Electrons are tightly bound in innermost orbits.
  - Electrons in outermost orbits are loosely bound.

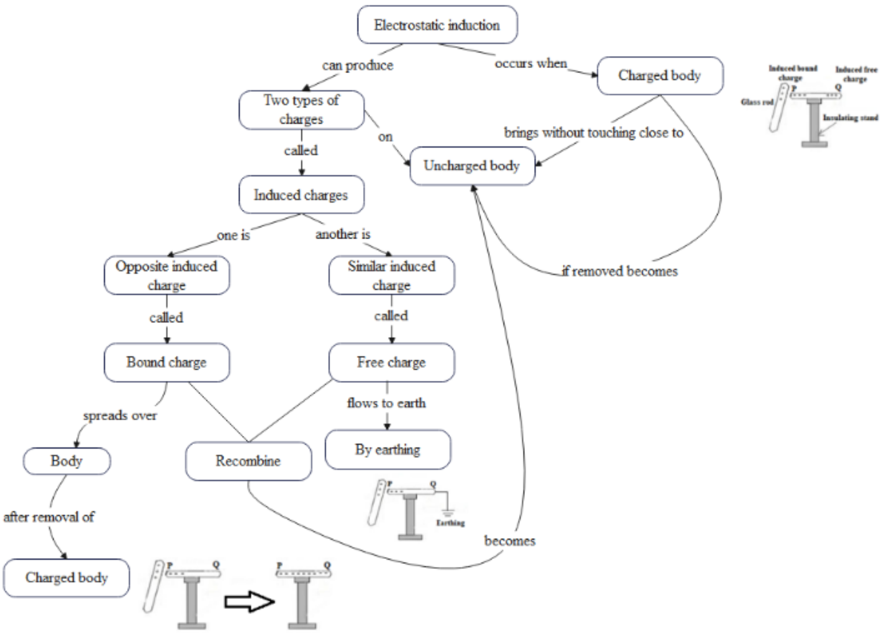
- Electrons in outermost orbit can be easily knocked out by creating a charge on it.

(5 min)

- Furthermore, Explain the process of electrostatic induction phenomena by presenting another concept map below.



- Also, elaborate the electrostatic induction phenomenon by showing another concept map as follows:



(5 min)

- Also, differentiate all the concepts into sub-concepts in the concept map that give the information of the electrostatic induction. by linking with appropriate verbs.
- Finally, reconcile integration of all sub concepts related with the electrostatic induction in the concept map providing with illustrations to get final propositions as:
  - Electrostatic induction can produce two types of charges.
  - Electrostatic occurs when charged body bring without touching close to uncharged body.
  - Charge which induces charge on uncharged body is called as inducing charge.
  - Opposite induced charge is called bound charge.
  - Similar induced charge is called free charge.

- Bound charge and free charge can recombine to become uncharge a charged body by removing the surrounding charged body, i.e., inducing charge.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - Explain modern theory of electrification.
    - What is the electrostatic induction?
    - Define inducing charge.
    - What are free charge and bound charge?
    - Explain briefly the process of electrostatic induction.

Assignment and closure

(5 min)

- Explain modern theory of electrification.
- Describe the process of electrostatic induction. Also, discuss how this phenomenon is related with our daily life consequences.
- Draw a well labelled diagram of process of electrostatic induction.

Episode - Three

Topics: Charging by electrostatic induction

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 566-567.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 91-93.

Learning Outcome:

- Understand the principle of electrostatic induction.
- Define the terms involved in process of electrostatic induction.
- Describe charging process by electrostatic induction either by positively or negatively.

In class activity (45 min)

Introducing (10*min*)

- Warm up the students about the previous class by asking few questions about
    - Types of charge with examples
    - Electrification process
    - Electrostatic induction
    - Process of earthing
    - Electrostatic induction

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

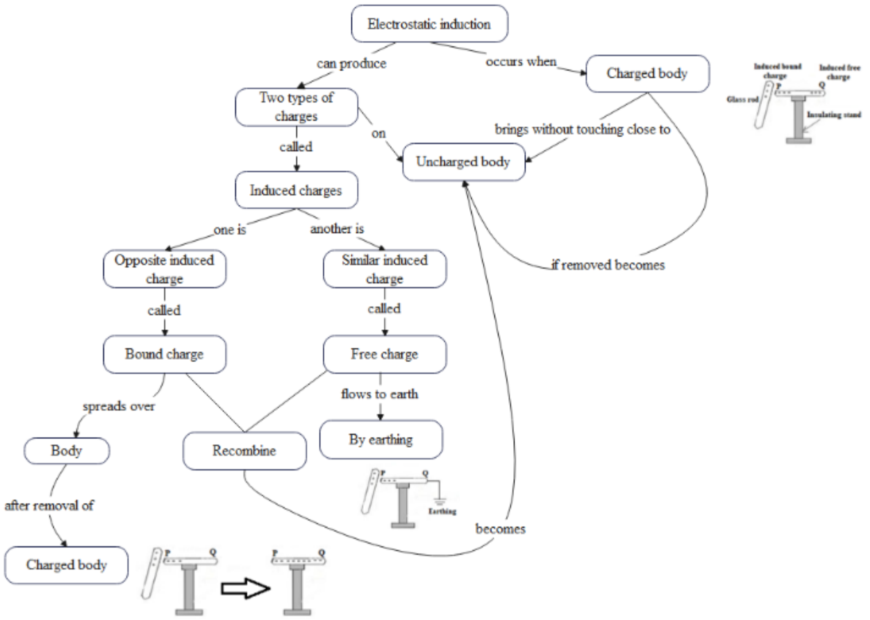
(5 min)

- Present the term charging positively by induction as an advance organizer.
- Present the term charging negatively by induction as an advance organizer.

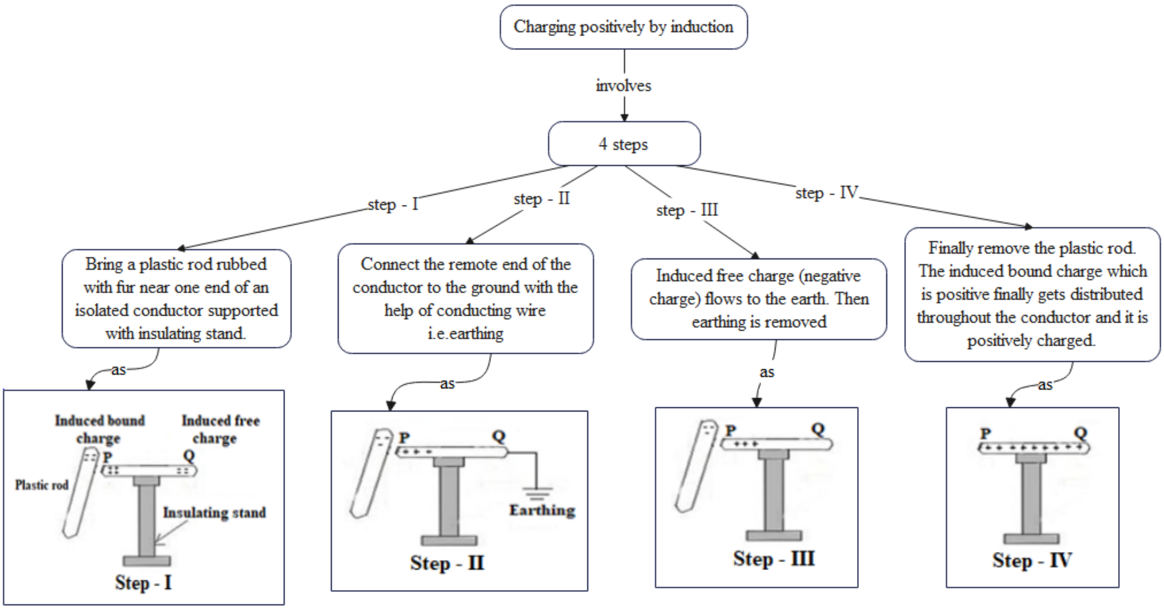
Phase – II: Presentation of learning Task or Material

(5 min)

- Define all the process of electrification by presenting concept map relating electrostatic induction.



- Also, elaborate the steps involved in charging experimental body positively by electrostatic induction by showing another concept map as:



Charging positively by induction

4 steps

Bring a plastic rod rubbed with fur near one end of an isolated conductor supported with insulating stand.

Connect the remote end of the conductor to the ground with the help of conducting wire i.e.earthing

Induced free charge (negative charge) flows to the earth. Then earthing is removed

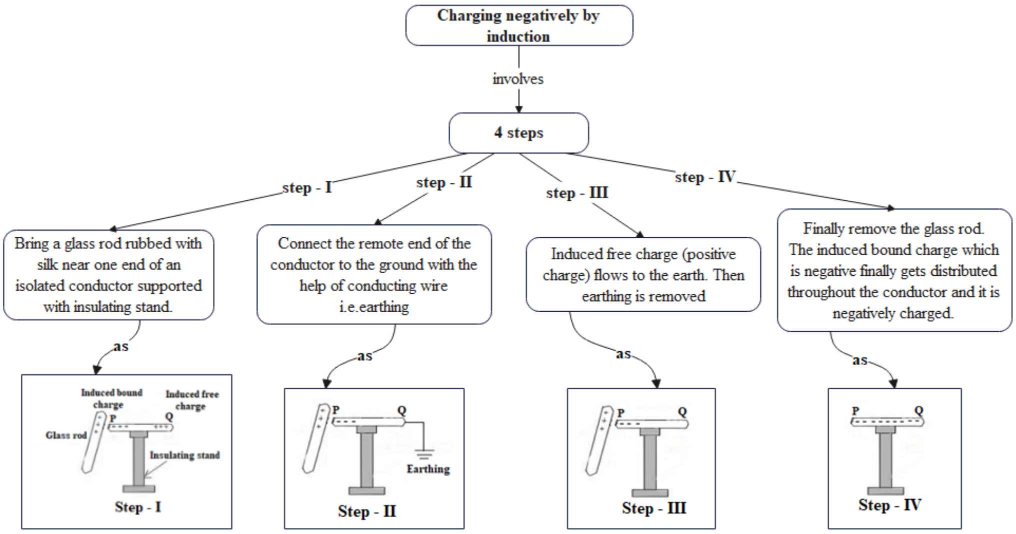
Finally remove the plastic rod. The induced bound charge which is positive finally gets distributed throughout the conductor and it is positively charged.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the charging experimental body with positive charge by electrostatic induction by linking with appropriate verbs.
- Describe followings steps involved in charging positively uncharged body by electrostatic induction by showing same concept map:
- Also, reconcile integration of all sub concepts related with the process of charging positively uncharged body by electrostatic induction by showing same concept map providing with illustrations to get final propositions as:
    - Similar charge repels and dissimilar charge attracts.
    - Positive bound charges are strongly held together with negatively charged body present nearby experimental body.
    - Negative free charge can easily flow towards the earth when earthing.

(5 min)

- Furthermore, explain the process of the steps involved in charging experimental body negatively by electrostatic induction by showing another concept map as:



(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the charging experimental body with negative charge by electrostatic induction by linking with appropriate verbs.
- Describe followings steps involved in charging negatively uncharged body by electrostatic induction by showing same concept map:
- Also, reconcile integration of all sub concepts related with the process of charging negatively uncharged body by electrostatic induction by showing same concept map providing with illustrations to get final propositions as:
  - Similar charge repels and dissimilar charge attracts.
  - Negative bound charges are strongly held together with positively charged body present nearby experimental body.
  - Positive free charge can easily flow towards the earth when earthing.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - Explain modern theory of electrification.
    - What is the electrostatic induction?
    - Define inducing charge.
    - What are free charge and bound charge?
    - Explain briefly the charging process of electrostatic induction.

Assignment and closure

(5 min)

- Explain modern theory of electrification.
- Describe the steps involved in the process of charging positively by an electrostatic induction with well labelled diagram.
- Describe the steps involved in the process of charging negatively by an electrostatic induction with well labelled diagram.

Episode - Four

Topics: Faraday’s Ice pail experiment

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 569-572.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 96-98.

Learning Outcome:

- Recall the principle of electrostatic induction.
- Prove induced positive charges = induced negative charges using Faraday’s Ice pail first experiment.
- Diagnose induced positive or negative charges = inducing charges using Faraday’s Ice pail second experiment.

In class activity (45 min)

Introducing (10*min*)

- Warm up the students about the previous class by asking few questions about
    - Types of charge with examples
    - Electrification process
    - Electrostatic induction
    - Process of earthing

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

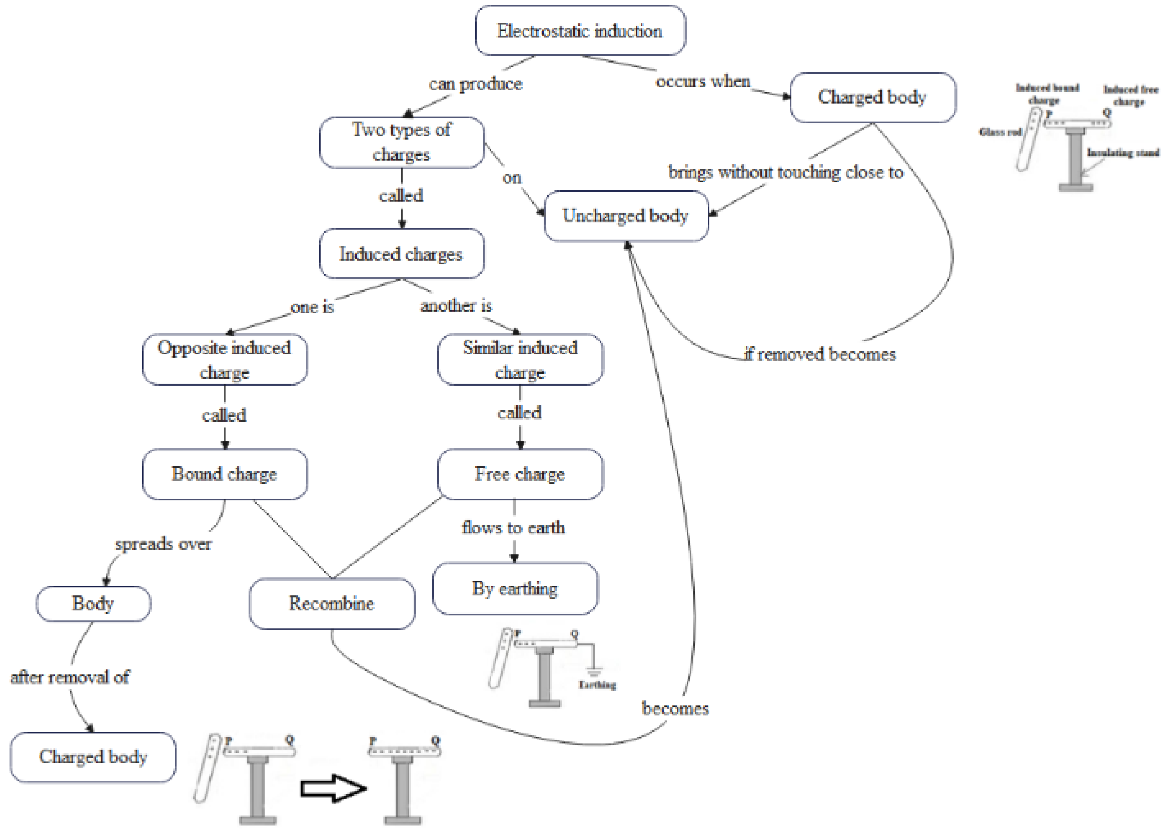
(5 min)

- Present the term Faraday’s Ice pail first experiment as an advance organizer.
- Present the term Faraday’s Ice pail second experiment as an advance organizer.

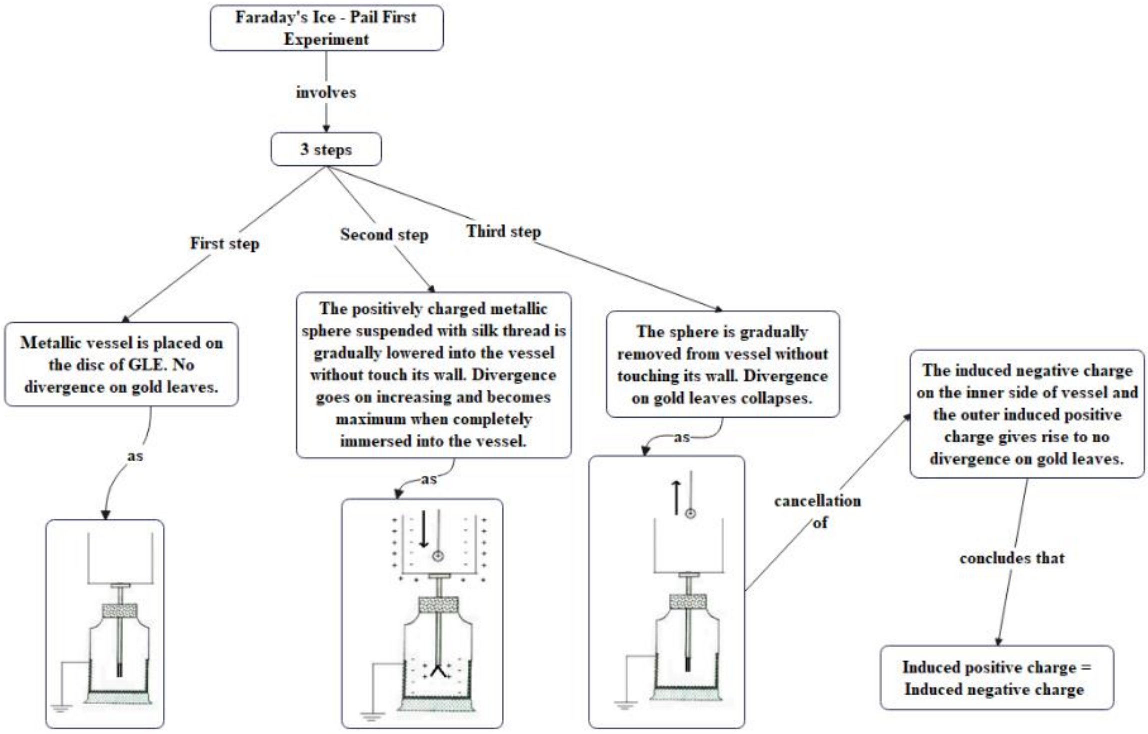
Phase – II: Presentation of learning Task or Material

(5 min)

- Define all the terms involved in electrostatic induction by presenting concept map as follows:



- Also, explain the steps involved in Faraday’s Ice pail first experiment by showing another concept map as:

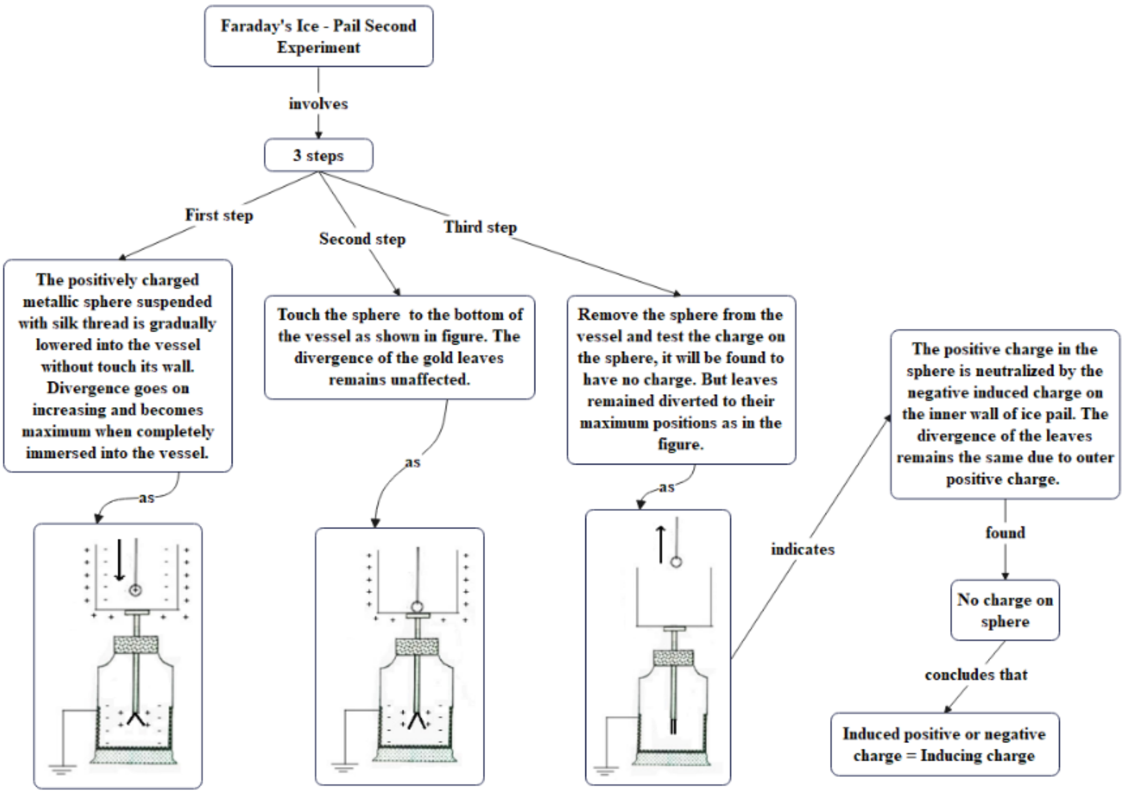


(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the Faraday's Ice pail first experiment by linking with appropriate verbs.
- Describe steps involved in the Faraday's Ice pail first experiment by showing same concept map:
- Also, reconcile integration of all sub concepts related with the Faraday's Ice pail first experiment by showing same concept map providing with illustrations to get final propositions as:
  - Similar charge repels and dissimilar charge attracts.
  - Positive bound charges are strongly held together with negatively charged body present nearby experimental body.
  - Negative free charge can easily flow towards the earth when earthing.
  - Induced positive charges = Induced negative charges

(5 min)

- Furthermore, explain the steps involved in Faraday’s Ice pail second experiment by showing another concept map as:



Faraday's Ice - Pail Second Experiment

3 steps

The positively charged metallic sphere suspended with silk thread is gradually lowered into the vessel without touch its wall. Divergence goes on increasing and becomes maximum when completely immersed into the vessel.

Touch the sphere to the bottom of the vessel as shown in figure. The divergence of the gold leaves remains unaffected.

Remove the sphere from the vessel and test the charge on the sphere, it will be found to have no charge. But leaves remained diverted to their maximum positions as in the figure.

The positive charge in the sphere is neutralized by the negative induced charge on the inner wall of ice pail. The divergence of the leaves remains the same due to outer positive charge.

No charge on sphere

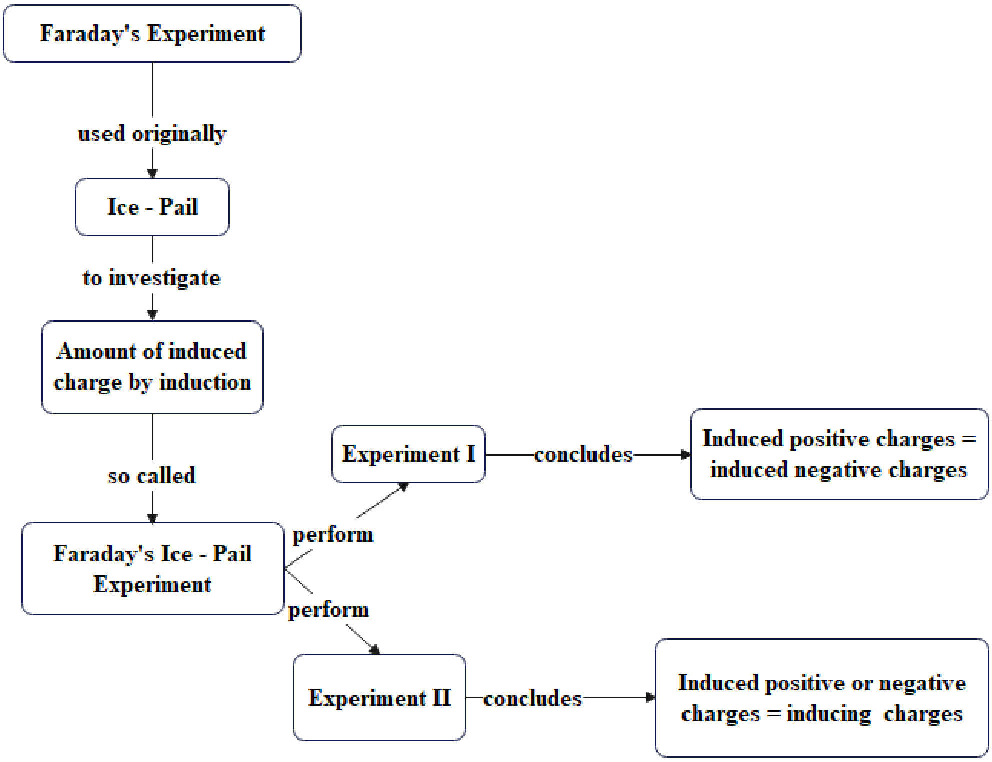
Induced positive or negative charge = Inducing charge

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the Faraday’s Ice pail second experiment by linking with appropriate verbs.
- Describe steps involved in the Faraday’s Ice pail second experiment by showing same concept map:
- Also, reconcile integration of all sub concepts related with the Faraday’s Ice pail second experiment by showing same concept map providing with illustrations to get final propositions as:
  - Similar charge repels and dissimilar charge attracts.

  - Positive bound charges are strongly held together with negatively charged body present nearby experimental body.
  - Negative free charge can easily flow towards the earth when earthing.
  - Induced positive or negative charges = Inducing charges

- Finally summarize the whole Faraday's ice pail experiment by presenting a concept map as follows:



Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
  - What is the electrostatic induction?
  - Define inducing charge.
  - What is induced charge?
  - What are free charge and bound charge?

- Explain briefly the charging process of electrostatic induction.

Assignment and closure

(5 min)

- Describe the steps involved in Faraday's ice pail first experiment with well labelled diagram. Discuss the result obtained from this experiment.
- Describe the steps involved in Faraday's ice pail second experiment with well labelled diagram. Discuss the result obtained from this experiment.

Episode - Five

Topics: Van de Graff generator

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 568-569
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 131-132.

Learning Outcome:

- Identify the key components of Van de Graff generator.
- Describe the working of generator.
- Explore various real-world applications of Van de Graff generators.
- Apply surface charge density and action of points in generator.

In class activity (45 min)

Introducing (10*min*)

- Warm up the students about the previous class by asking few questions about
    - Types of charge with examples
    - Electrostatic conduction through dry and wet media.
    - Process of discharging or leakage of charges through sharp edges or corners

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

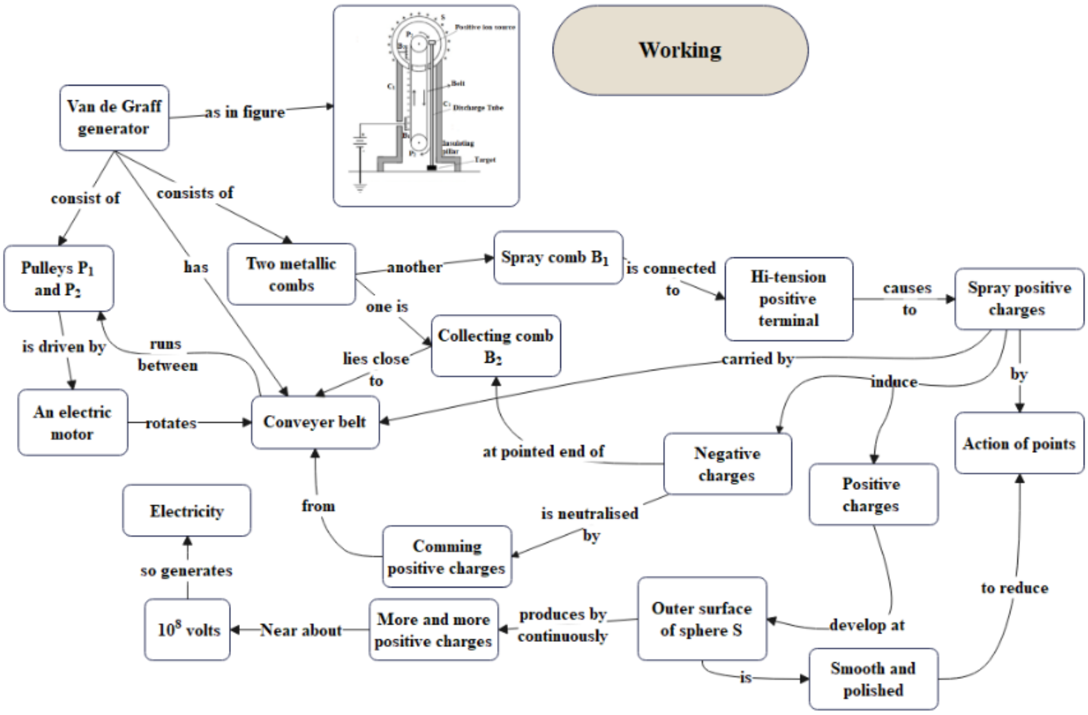
(5 min)

- Present the term Van de Graff Generator as an advance organizer.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe the key components of Van de Graff Generator and its construction by presenting concept map as follows:



- Also, explain the all the components with their function in developing charge by showing same concept map.
- Describe the process of action of points by showing same concept map.
- Explain the working principle of Van de Graff generators by presenting same concept map.

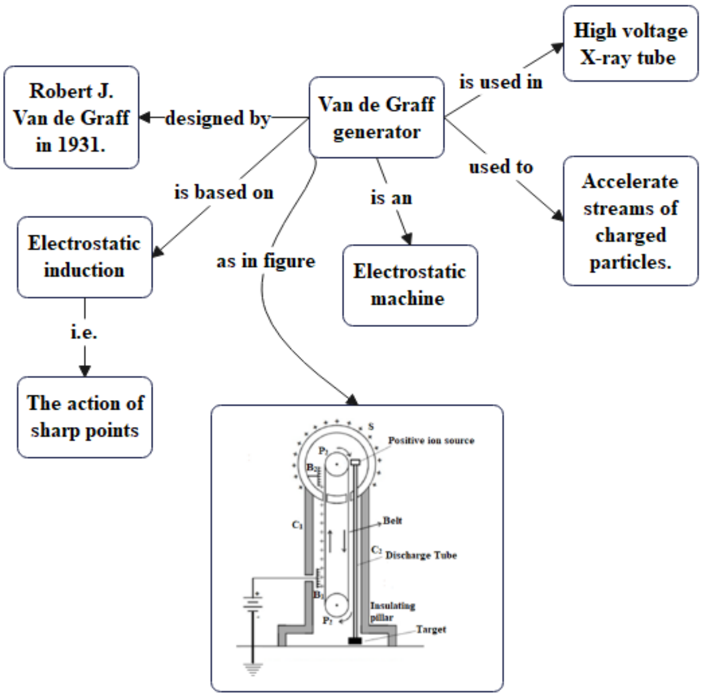
(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the Van de Graff generator by linking with appropriate verbs.

- Also, reconcile integration of all sub concepts related with the Van de Graff Generator by showing same concept map providing with illustrations to get final propositions as:
  - Surface charge density is maximum at the pointed ends of a spray combs.
  - Surface charge density depends upon the shape of conductors.
  - Van de Graff generator include the metal sphere, the motor, the belt, and the brushes.
  - Two opposite charges neutralize during recombination process.

(5 min)

Furthermore, explain the application of Van de Graff generators by showing another concept map as:



(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the application of Van de Graff Generators by linking with appropriate verbs.

- Also, reconcile integration of all sub concepts related with the application of van de Graff Generators by showing same concept map providing with illustrations to get final propositions as:
  - Van de Graff generator is used in high voltage X-ray tube.
  - Van de Graff generator is used to accelerate the charge particles.
  - Action of points is the main principle of Van de Graff Generator.
- Finally summarize the application of van de Graff generators with its designer by showing the same concept map.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
  - ➢ Define surface charge density?
  - ➢ Explain briefly the action of points?
  - ➢ What is the result produced from action of points?
  - ➢ What is the working principle of Van de Graff generators?
  - ➢ What are the key components of Van de Graff generators?
  - ➢ What is the role of the action of points in generators?
  - ➢ What are the applications of the Van de Graff generators in practical devices in real world?

Assignment and closure

(5 min)

- Research and describe at least three real-world applications of Van de Graff generators in scientific research or industrial settings. Explain how the generator’s unique properties are utilized in each application.

- What is the significance of surface charge density in Van de Graff generators?
- How does the action of points impact the breakdown voltage of a system?
- What safety measures should be taken when dealing with points and high electric fields?
- Can the action of points be used to enhance or control electric discharge phenomena?
- Investigate the historical significance of R.J. Van de Graff’s contribution to physics and the development of the generator. Prepare a short biography of van de Graff and explain how his work impacted the field of electrostatics.

Episode - Six

Topics: Coulomb's law

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 574-575.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 102-104.

Learning Outcome:

- Articulate Coulomb's law in own words.
- Calculate the magnitude of the electrostatic force between two-point charges of known magnitudes and separation distance.
- Understand that the electrostatic force acts along the line connecting the charges.
- Comprehend the principle of superposition to find the resultant force on a charge due to multiple other charges.
- Understand the meaning of permittivity.

In class activity (45 min)

Introducing (10*min*)

- Start the class by asking the students about
    - ➢ If they have ever experienced a balloon sticking to a wall or their hair.
    - ➢ Allow them to share their experiences and observations.
    - ➢ Why the balloon sticks to the wall or attracts small objects.
    - ➢ Types of charge with examples

- ➢ Electrostatic conduction through dry and wet media.
- ➢ Process of discharging or leakage of charges through sharp edges or corners

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

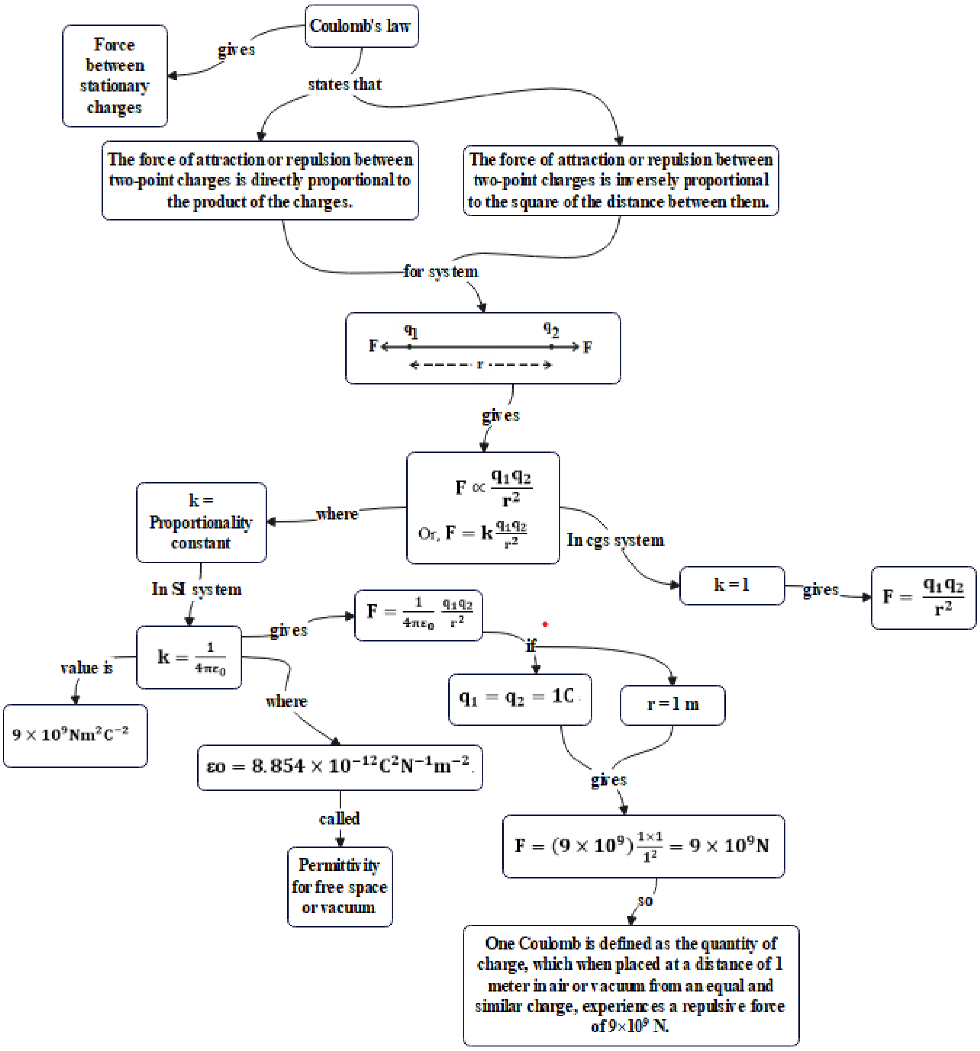
(5 min)

- Present the term Coulomb's law as an advance organizer.

Phase – II: Presentation of learning Task or Material

(5 min)

Describe and state Coulomb's law by presenting concept map as follows:



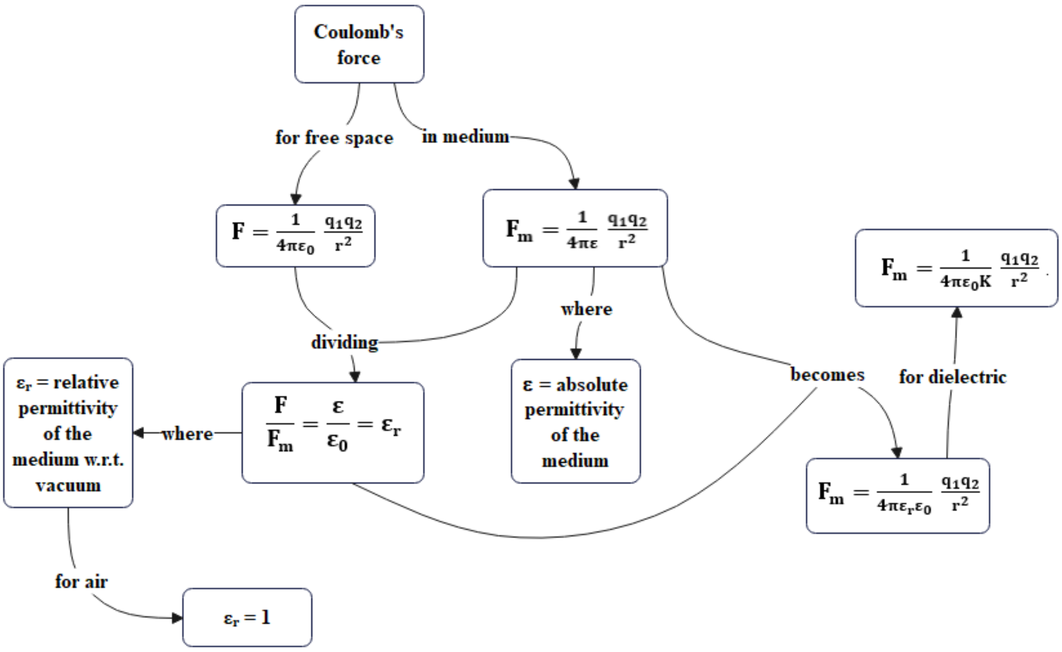
- Also, explain the equation of force experienced between two stationary charges in free space and medium except free space by showing same concept map.
- Describe the coulomb's constant $k = \frac{1}{4\pi\varepsilon_0}$ by showing same concept map.
- Differentiate all the concepts into sub-concepts in the concept map that give the information of the Coulomb's law by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the Coulomb's law by showing same concept map providing with illustrations to get final propositions as:
  - Coulomb's measured force between two stationary charges.
  - Resultant force due to multiple charges can be determined by using superposition principle i.e., by vector addition as $F = F_1 + F_2 + F_3 + \cdots\cdots\cdots\cdots + F_n$.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the Coulomb's law by linking with appropriate verbs.

(5 min)

- Furthermore, explain the meaning of permittivity by showing another concept map as:



(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the permittivity by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the permittivity by showing same concept map providing with illustrations to get final propositions as:
  - Permittivity for free space is denoted by ε_0 and for media ε.
  - Relative permittivity can be denoted as ε_r and can be expressed as $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$
  - Relative permittivity for air is 1.
- Finally summarize the concept of permittivity by showing the same concept map.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - State the Coulomb’s law.
    - How would you explain it to someone who is unfamiliar with the concept?
    - Can you describe the relationship between the magnitude of the electrostatic force and the distance between two charges, as stated in Coulomb’s law?
    - What are the values of Coulomb’s constant (k) in cgs and SI system of unit.
    - Define permittivity and explain its significance in electrostatic interactions.
    - Explain briefly the action of points?

Assignment and closure

(5 min)

- What is Coulomb's law, and how does it describe the electrostatic force between two-point charges?
- State Coulomb's law mathematically and explain the significance of each term in the equation.
- Describe the relationship between the magnitude of the electrostatic force and the distance between two charges, as expressed in Coulomb's law.
- What is the principle of superposition in the context of Coulomb's law? How does it apply to multiple charges in an electrostatic system?

- Define permittivity and explain its role in electrostatic interactions between charged objects.
- Distinguish between vacuum permittivity (ε_o) and relative permittivity (ε_r) of a material. How are they related to each other?
- Suppose you have three-point charges, q_1, q_2, and q_3, arranged in a straight line. What will be the direction of the net force on charge q_1 if q_2 and q_3 have the same sign, and how will this force change if the distance between q_1 and q_2 is doubled?
- Discuss the significance of Coulomb's constant (k) in the context of Coulomb's law and how it varies depending on the system of units used.
- Calculate the magnitude of the electrostatic force between two-point charges: $q_1 = 4\ \mu C$ and $q_2 = -6\ \mu C$, separated by a distance of 8 cm.
- Three-point charges, $q_1 = 2$ nC, $q_2 = 5$ nC, and $q_3 = -3$ nC, are placed at the vertices of an equilateral triangle with sides of 10 cm. Calculate the net electrostatic force experienced by q_1.

Episode – Seven

Topics: Electric field

- **Electric field intensity**
- **Electric field intensity due to a point charge**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 575-579.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 108-111.

Learning Outcome:

By the end of this class period, students should be able to:

- Define and explain the concept of electric fields in the context of electrostatics.
- Understand the relationship between electric fields and electric charges, including the behavior of positive and negative charges in electric fields.
- Calculate the electric field intensity (electric field strength) at a specific point in space due to one or more-point charges.
- Apply Coulomb's Law to determine the magnitude of the electric field intensity produced by a single point charge.
- Comprehend the concept of superposition and use it to find the net electric field intensity at a point due to multiple point charges.
- Interpret and draw electric field lines to visualize electric fields around point charges.

- Recognize the factors affecting the magnitude and direction of electric field intensity, such as distance and charge.

In class activity (45 min)

Introducing (10*min*)

- Start the class by asking the students about
  - any prior knowledge of electric fields, electric field intensity, or point charges.
  - If they had encountered these concepts before in any context.
  - If they had ever experienced a shock when touching a doorknob or felt a static cling.
  - If they could explain what positive and negative charges were and if they knew how like charges and opposite charges interacted.
  - Relation between electric fields and gravitational fields to consider how these fields were similar and different.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

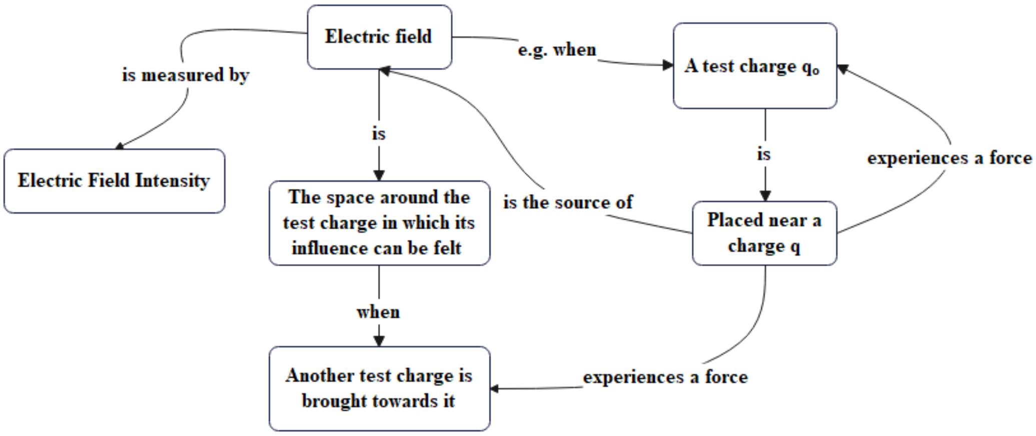
(5 min)

- Present the term Electric field as an advance organizer.
- Present the term electric field intensity as an advance organizer.

Phase – II: Presentation of learning Task or Material

(5 min)

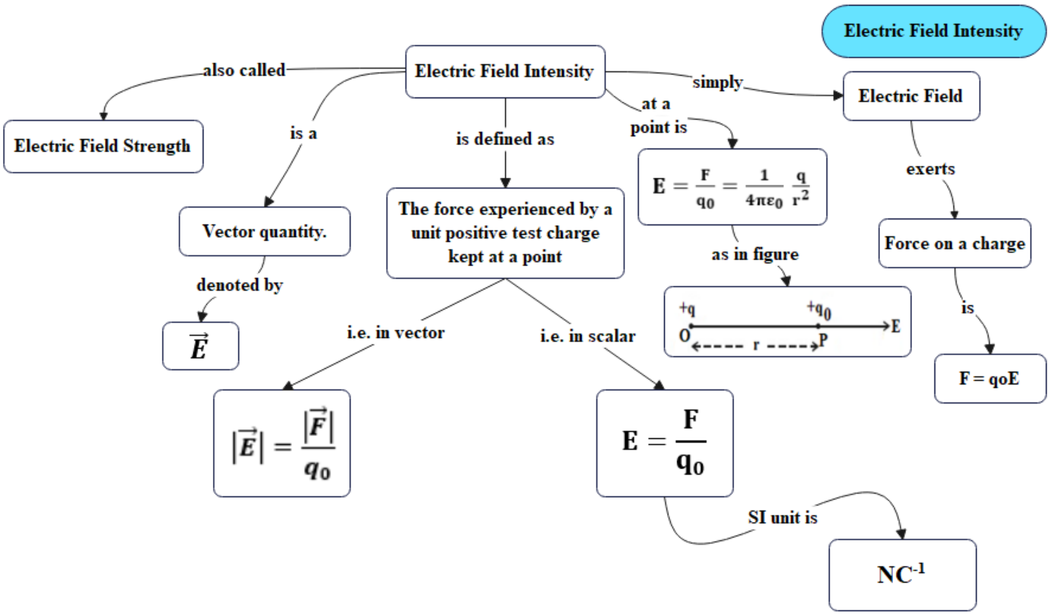
- Describe and define electric field by presenting concept map as follows



- Also, explain the electric field is the region in which any charge experiences force by showing same concept map.
- Describe an electric field is the measure of electric field intensity by showing same concept map.
- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electric field by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electric field by showing same concept map providing with illustrations to get final propositions as:
  - Electric field is a space around a charge in which its effect can be felt.
  - Electric field is measured by electric field intensity.

(5 min)

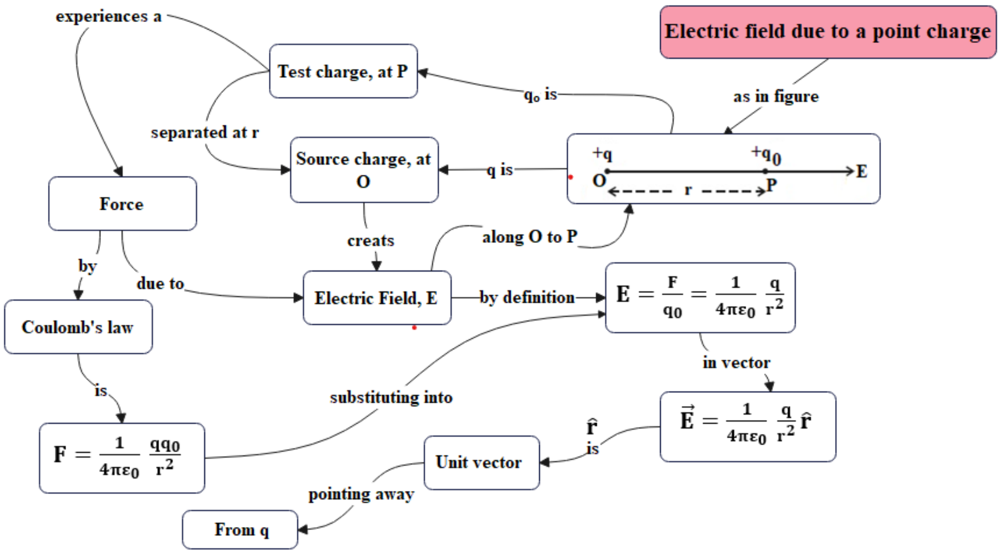
- Define electric field intensity by presenting another concept map as:



- Also, explain the electric field intensity is the force experienced by a unit positive charge kept at point by showing same concept map.
- Describe an electric field intensity as a vector quantity by showing same concept map.
- Express electric field intensity by formula E = $\frac{q}{4\pi\varepsilon_0 r^2}$ in SI system for free space in same concept map.
- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electric field intensity by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electric field intensity by showing same concept map providing with illustrations to get final propositions as:
  - Electric field is a space around a charge in which its effect can be felt.
  - Electric field is measured by electric field intensity.

(5 min)

- Furthermore, describe to derive an expression of electric field intensity due to a point charge by showing another concept map as:



- Also, describe how coulomb’s law is related with the electric field intensity by showing same concept map.
- Express electric field intensity at a point in vector form by formula $\vec{E} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{r}$ in SI system for free space in same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electric field intensity at a point due to point charge by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electric field intensity at a point due to point charge by showing same concept map providing with illustrations to get final propositions as:
    - Electric field intensity can be expressed by $\vec{E}$ in vector form.
    - Electric field intensity at a point can be expressed as $\vec{E} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{r}$ in vector notation where $\hat{r}$ is a unit vector.

- Finally summarize the concept of electric field intensity due to a point charge by showing the same concept map.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - Could anyone provide an example of an everyday situation where you might have experienced an electric field?
    - How would you describe the interaction between two positively charged objects, based on what we’ve discussed so far?
    - What was your understanding of an electric field, and how did it relate to the concept of charge?
    - Can you think of an example where knowing the direction of an electric field could be important?
    - In a scenario with two-point charges, how would you calculate the electric field intensity at a specific location?
    - What was the significance of Coulomb’s law in understanding electric fields, and why did we use it?
    - How did the superposition principle help us analyze electric fields in scenarios with multiple charges?

Assignment and closure

(5 min)

- What is electric field? Explain how knowledge of permittivity affects the behavior of electric fields in different materials. Provide an example of a real-world application where this understanding is crucial.
- Define electric field intensity? Derive a relation of electric field intensity at a point due to a charge in free space.
- What is the principle of superposition in the context of electric field intensity? How does it apply to find resultant electric field intensity due to multiple charges in an electrostatic system?
- Consider two-point charges $q_1 = 3\ \mu C$, and $q_2 = -5\ \mu C$, placed 10 cm apart in a vacuum. Calculate the electric field intensity at a point P, located 5cm from charge q_1 along the line connecting the charges.
- Sketch the electric field lines produced by two positive point charges, $q_1 = 2$ nC, and $q_2 = 2$ nC, placed 4 cm apart in air.

Episode – Eight

Topics: - Electric Flux

- Gauss’s Theorem

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 576-577.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 112-114.

Learning Outcome:

By the end of this class period, students should be able to:

- define and explain the concept of electric flux in the context of electric fields.
- calculate electric flux through closed surfaces for uniform and non-uniform electric fields.
- understand the units of electric flux and perform unit conversions.
- describe the relationship between electric flux and the electric field, considering field orientation.
- apply the concept of electric flux to practical situations and geometric shapes.
- state Gauss's theorem and its significance in studying electric fields.
- prove Gauss’s theorem in studying electric fields.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge or familiarity with the concept of electric flux.

- whether they had encountered Gauss's Theorem or Gauss's Law in their previous studies.
- if they had any real-life experiences or examples related to electric charges or electric fields.
- whether they could explain what electric field intensity was and how it related to electric flux.
- if they understood the significance of closed surfaces in the context of electric flux and Gauss's Theorem.
- if they were aware of the mathematical tools, such as integration and calculus, that were commonly used when studying Gauss's Theorem.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

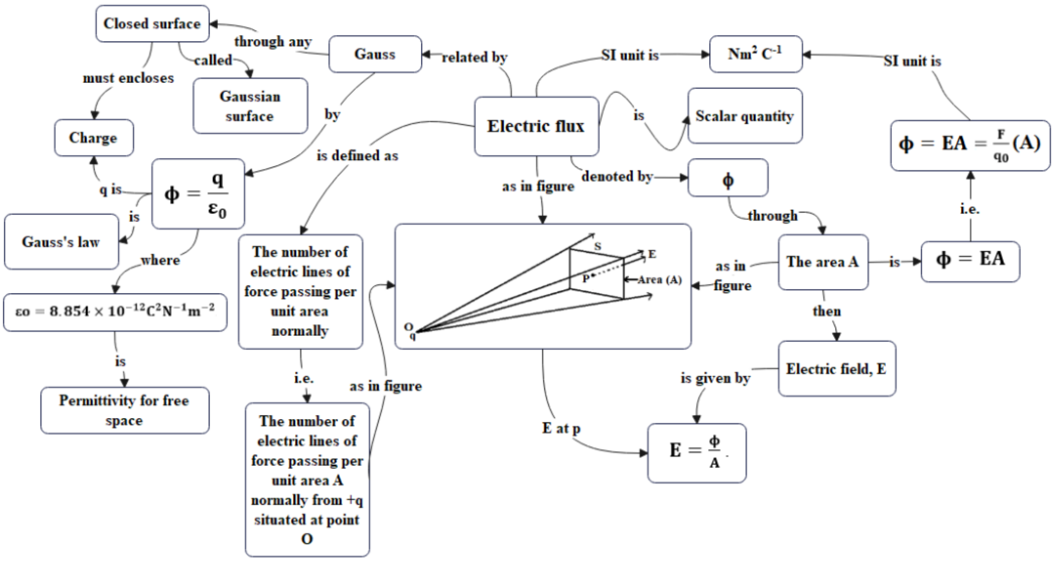
(5 min)

- Present the term Electric flux as an advance organizer.
- Present the term Gauss’s theorem as an advance organizer.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe and define electric lines of force and electric force by presenting concept map as follows:



- Also, explain the electric flux is the number of electric lines of force passing per unit area normally by showing same concept map.
- Describe an electric flux is the measure of electric field intensity i.e., electric flux per unit area termed as electric field intensity ($E = \frac{\phi}{A}$) by showing same concept map.

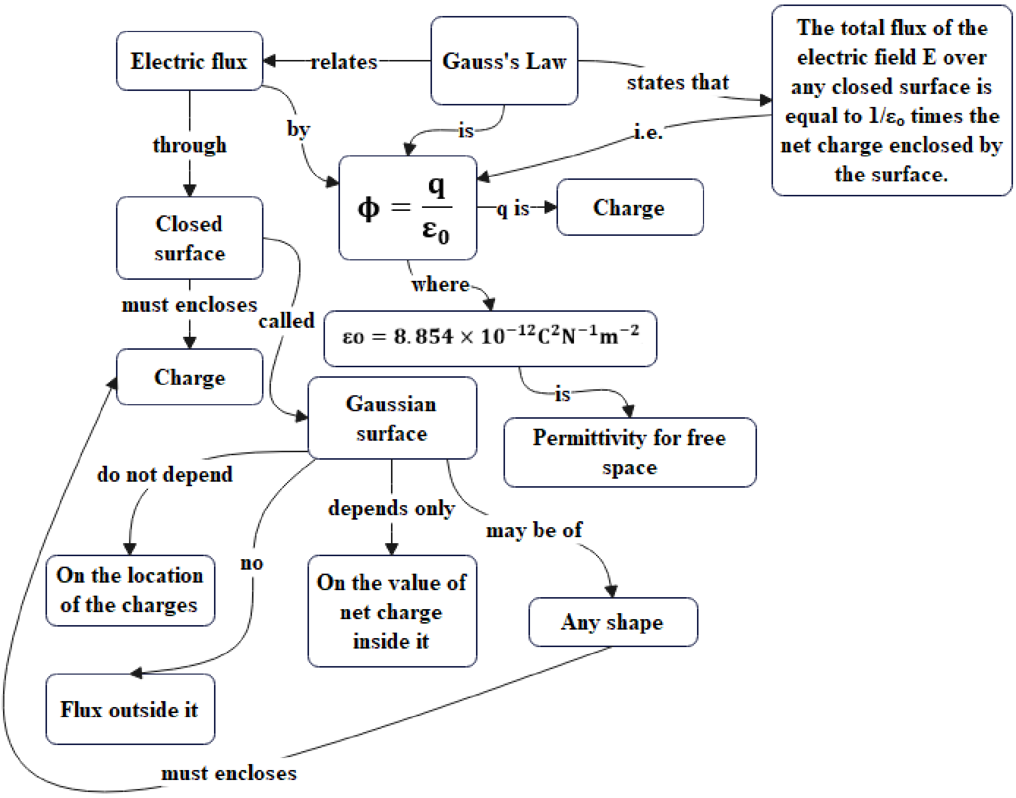
(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electric flux by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electric flux by showing same concept map providing with illustrations to get final propositions as:
    - Electric flux is a scalar quantity.
    - Electric field intensity due to any charge distribution is measured by electric flux per unit area.
    - Electric flux is related to Gauss's theorem.

- Finally summarize the concept of electric flux by showing the same concept map.

(5 min)

- State gauss's theorem by presenting another concept map as:



- Also, explain the total electric flux over any closed surface is $1/\varepsilon_0$ times the net charge enclosed by the surface.

- Electric flux through closed surface must encloses charge by showing same concept map.

- Describe an electric field intensity as a vector quantity by showing same concept map.

- Express electric field intensity by formula $E = \frac{\phi}{A}$ in same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the Gauss's theorem by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the Gauss's theorem by showing same concept map providing with illustrations to get final propositions as:
    - Gauss's theorem relates electric flux through any closed surface called gaussian surface.
    - Electric field is measured by electric flux and depends upon the charge enclosed by Gaussian surface.
- Finally summarize the concept of Gauss's theorem by showing the same concept map.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - ➢ Could you explain what electric flux is and why it's important in understanding electric fields?
    - ➢ What is Gauss's theorem, and how does it relate to electric charge and electric fields?
    - ➢ Calculate the electric flux through a closed surface for a uniform electric field of magnitude E when the surface is perpendicular to the field.

Assignment and closure

(5 min)

- Define electric flux in your own words, providing a concise explanation of its significance in understanding electric fields.
- Calculate the electric flux through a closed surface of your choice in the scenario you selected. Clearly state the assumptions and principles used in your calculation.
- State Gauss's theorem and prove it.

Episode – Nine

Topics: Applications of Gauss’s theorem

- the electric field intensity due to a charged sphere

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 577-578.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 114-115.

Learning Outcome:

By the end of this class period, students should be able to:

- articulate the fundamental principles of Gauss’s theorem and its application to the calculation of electric field intensity.
- calculate the electric field intensity at various points inside and outside a charged conducting sphere using Gauss's Theorem.
- analyze how the electric field varies with distance from the center of the charged sphere.
- apply Gauss's Theorem to determine the electric field intensity due to an infinite plane sheet of charge with uniform charge distribution.
- understand how the electric field behaves with varying distances from the plane.
- solve practical problems involving real-world scenarios, including those with charged spheres and infinite plane sheets, by employing Gauss's Theorem.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- if they have any prior knowledge or familiarity with the concept of electric flux.
- if they can provide a brief explanation of what electric flux represents in the context of electric fields.
- if they can recall any key principles or applications associated with Gauss's Theorem.
- to share any personal experiences or examples related to electric charges or electric fields that they may have encountered in their daily lives.
- to discuss instances where they observed or interacted with electric fields.
- if students can explain what electric field intensity is and how it relates to electric flux.
- if they understand the significance of closed surfaces, particularly in the context of electric flux and Gauss's Theorem.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

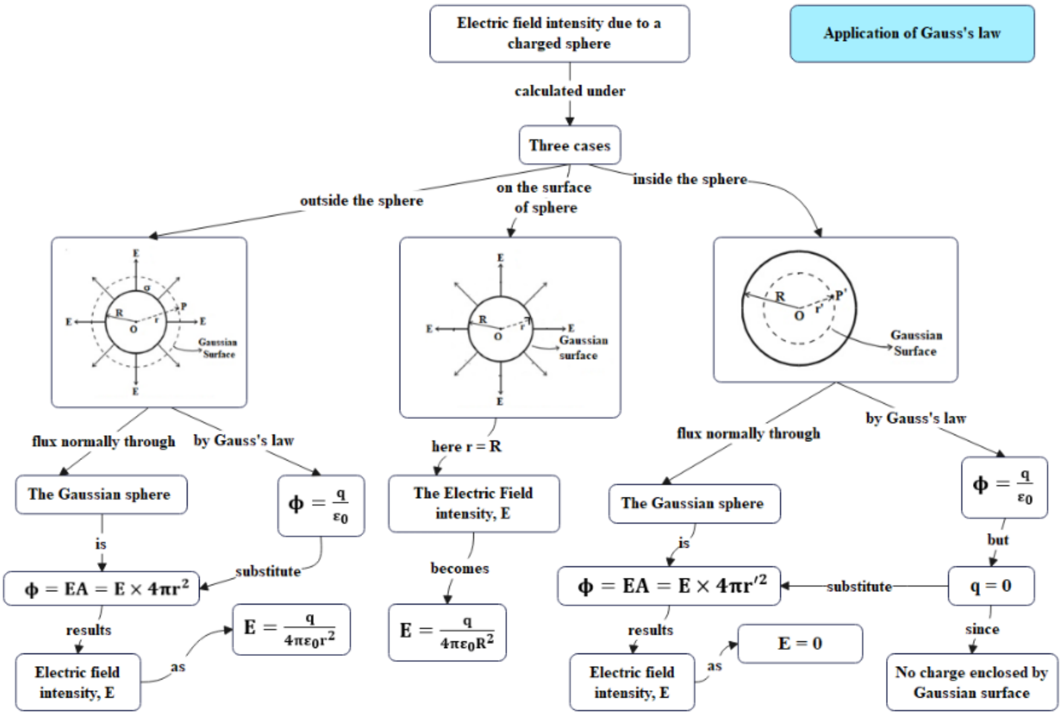
(5 min)

- Presented the term Electric field intensity due to a charged sphere as an advance organizer.
- Provide a brief overview of the related term with electric field intensity due to a charged sphere.

Phase – II: Presentation of learning Task or Material

(5 min)

- Define electric field intensity and calculate electric field intensity due to a uniformly distributed charged sphere using Gauss's theorem by presenting concept map as follows:



- Describe the drawing of Gaussian surface as in the form of concentric spheres drawn in case of uniformly charged sphere by showing same concept map.
- Explain the calculation of total electric flux through Gaussian surface by considering three cases like outside the sphere, on the sphere, and inside the sphere by showing same concept map.

(5 min)

- State the gauss theorem and show the relation of flux with charge enclosed q by Gaussian surface as $\phi = \frac{q}{\epsilon_0}$.

- Explain the charge enclosed inside the Gaussian surface as in the case of inside the charged sphere is assumed to be zero.

(5 min)

- Relate the flux calculated through Gaussian surface with $\phi = \frac{q}{\epsilon_0}$.
- Describe the calculation of electric field intensity due to uniformly charged sphere using Gauss's theorem by showing same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electric field intensity due to uniformly charged sphere by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electric field intensity due to uniformly charged sphere by showing same concept map providing with illustrations to get final propositions as:
  - Electric flux is inversely proportional to square of the radius of gaussian surface.
  - No charge is enclosed by gaussian surface inside the charged sphere.
- Finally summarize the concept of electric field intensity due to uniformly charged sphere by showing the same concept map.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
  - ➢ Can you recall and explain the key principle of Gauss's Theorem as applied to uniformly charged sphere?

- Imagine a charged conducting sphere with a non-uniform charge distribution. How would you use Gauss's Theorem to calculate the electric field at various points?

Assignment and closure

(5 min)

- Apply Gauss's Theorem to calculate the electric field intensity at various points both inside and outside the sphere.
- Provide a detailed explanation of your calculations and observations, emphasizing how Gauss's Theorem aids in solving such problems.

Episode - Ten

Topics: Electric potential

- **Electric potential due to a point charge**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 580-581.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 119-124.

Learning Outcome:

By the end of the lessons, students should be able to:

- explain the concept of electric potential (electric potential energy per unit charge) in the context of electric fields and point charges.
- calculate the electric potential at a specific point in space due to a point charge, taking into account the charge's magnitude and distance.
- recognize that electric potential is a scalar quantity and understand its significance in electrostatics.
- analyze how the electric potential due to a point charge depends on the magnitude of the charge and the distance from the charge.
- apply mathematical tools, including algebra and calculus, to perform calculations related to electric potential due to a point charge.
- apply the concept of electric potential due to a point charge to solve numerical problems, connecting theoretical knowledge to real-world scenarios.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge or familiarity with the concept of electric charge and potential due to a point charge.
- if they can provide a brief explanation of what electric potential represents in the context of electric fields.
- any real-life experiences or examples related to electric charges or electric fields that they may have encountered.
- if they can explain what electric field intensity is and how it relates to electric potential.
- if they are aware of the mathematical tools, such as integration and calculus.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

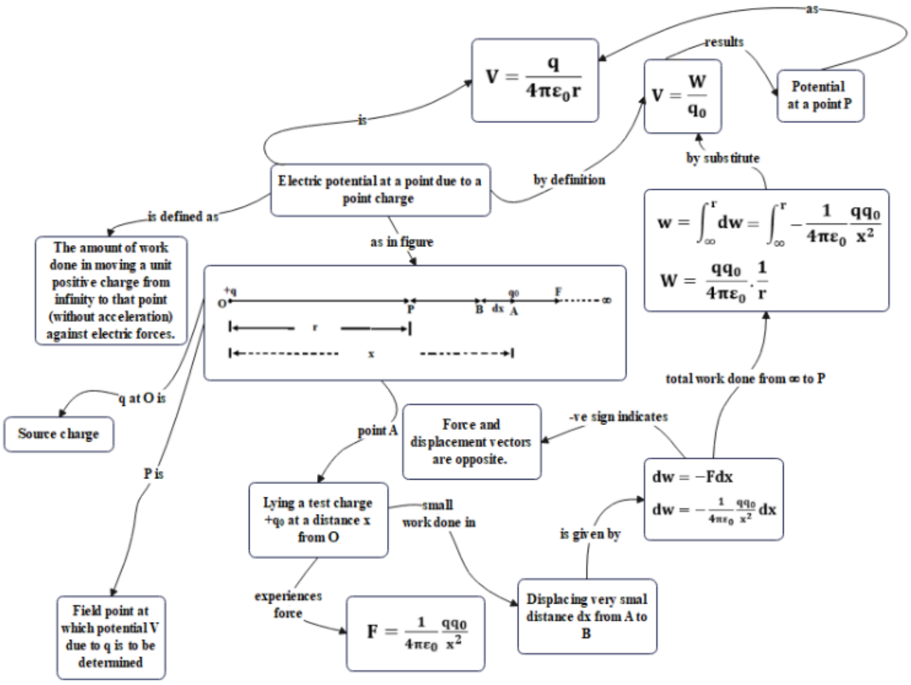
(5 min)

- Present the term Electric potential due to a point charge as an advance organizer.
- Give a brief overview of terms related to electric potential due to point charge.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe and define electric field by presenting concept map as follows:



- Defined electric potential as work done per unit charge in the context of electric fields and point charges by showing in same concept map.
- Discussed the formula for calculating electric potential at a specific point due to a point charge by providing the same concept map as $V = \frac{W}{q_0}$.

(5min)

- Worked through examples, illustrating step-by-step calculations involving expression of force experienced by positive charge q_0 in electric field developed by primary charge +q from infinity to any specific point inside electric field by providing the same concept map as $F = \frac{qq_0}{4\pi\varepsilon_0 r^2}$.

(5 min)

- Also, show the calculation of the small amount of work done dw in moving through very infinitesimal distance dx on concept map by using $dw = F \times dx$.

- Furthermore, calculated the total work done in moving from infinity to the point inside electric field by integrating from infinity to a fixed distance r from charge +q as

$$\mathrm{w} = \int_{\infty}^{\mathrm{r}} \mathrm{dw} = \int_{\infty}^{\mathrm{r}} -\frac{1}{4\pi\varepsilon_0}\frac{\mathrm{qq_0}}{\mathrm{x}^2}$$ in same concept map.

Here, negative sign is due to the opposite movement of charge against electrostatic force.

- Finally, calculated the potential by using $\mathrm{V} = \frac{W}{q_0}$ as $V = \frac{q}{4\pi\varepsilon_0 r}$.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electric potential at a point due to point charge by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electric potential at a point due to point charge by showing same concept map providing with illustrations to get final propositions as:
  - Electric potential is a scalar quantity.
  - Electric potential at a point due to point charge can be expressed as $V = \frac{q}{4\pi\varepsilon_0 r}$ in free space.
- Finally summarize the concept of electric potential at a point due to a point charge by showing the same concept map.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like

- Can you recall and explain the fundamental concept of electric potential due to a point charge?
- How would you describe the significance of electric potential in the context of electric fields and point charges?
- In what ways does electric potential differ from electric field intensity?
- How does the magnitude and distance of a point charge influence the electric potential it creates in its surroundings?
- Can you provide an example from daily life where understanding electric potential due to a point charge might be useful?

Assignment and closure

(5 min)

- What is electric potential due to point charge?
- Provide an example of a real-world application where the understanding of electric potential is crucial.
- Derive a relation of electric potential due to point charge in free space.
- ABC is an equilateral triangle of side 5cm. Charges of 100μC and 50μC are placed at A and B. Calculate the electric potential at C. (Given: $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 NC^{-2}m^{-2}$)

Episode - Eleven

Topics: Electric potential

- **Potential difference between two points**
- **Zero potential and potential at a point**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 580-584.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 120-123.

Learning Outcome:

By the end of the lessons, students should be able to:

- explain the concept of electric potential (electric potential energy per unit charge) in the context of electric fields and point charges.
- calculate the electric potential difference between two points, taking into account the charge's magnitude and distance.
- apply mathematical tools, including algebra and calculus, to perform calculations related to electric potential due to a point charge.
- calculate the potential at a point by taking the consideration of zero potential.
- apply the concept of electric potential difference to solve numerical problems, connecting theoretical knowledge to real-world scenarios.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge or familiarity with the concept of electric charge and potential due to a point charge.
- if they can provide a brief explanation of what electric potential difference represents in the context of electric fields.
- any real-life experiences or examples related to electric charges or electric fields that they may have encountered.
- if they can explain what electric field intensity is and how it relates to electric potential difference.
- if they are aware of the mathematical tools, such as integration and calculus.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

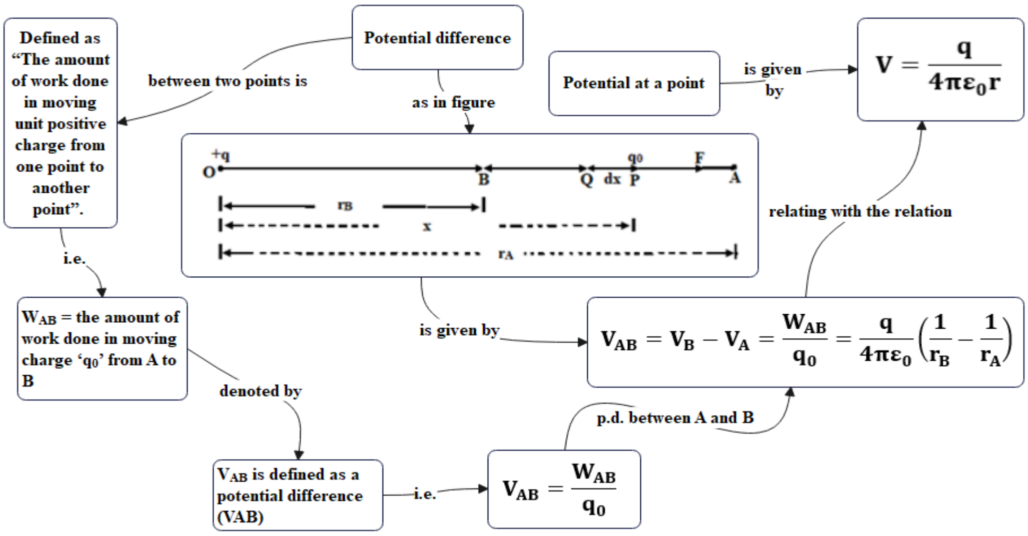
(5 min)

- Present the term Electric potential difference between points and zero potential as an advance organizer.
- Give a brief overview of terms related to Electric potential difference between points and zero potential.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe and define electric potential difference by presenting concept map as follows:



- Defined electric potential difference as work done per unit charge in the context of electric fields between two points and point charges by showing in same concept map.
- Discussed the formula for calculating electric potential difference between two points by providing the same concept map as $\mathrm{V} = \frac{W_{AB}}{q_0}$.

(5min)

- Worked through examples, illustrating step-by-step calculations involving expression of force experienced by positive charge q_0 in electric field developed by primary charge +q from one point to another point inside electric field by providing same concept map as

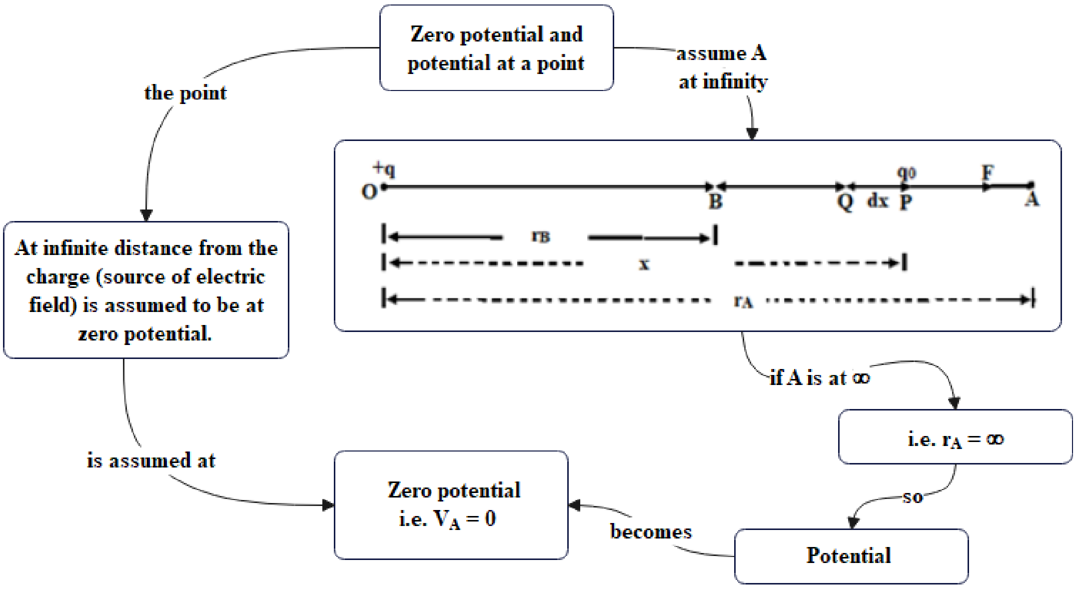
$$\mathrm{F} = \frac{qq_0}{4\pi\varepsilon_0 \mathrm{r}^2}$$

- Also, calculated the small amount of work done dw in moving through very infinitesimal distance dx on the same concept map by using $dw = \mathrm{F} \times \mathrm{dx}$
- Furthermore, calculated the total work done in moving from point A to the point inside electric field by integrating from point A to another point B at a distance r_A and r_B from charge +q as $W_{AB} = \int_{r_A}^{r_B} dw = \int_{r_A}^{r_B} -\frac{1}{4\pi\varepsilon_0}\frac{qq_0}{x^2}$ by providing same concept map.

  Here, negative sign is due to the opposite movement of charge against electrostatic force.
- In addition, calculated the potential by using $\mathrm{V} = \frac{W_{AB}}{q_0}$ as $V_{AB} = V_B - V_A = \frac{W_{AB}}{q_0} = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$

(5 min)

- Describe and define zero potential by presenting another concept map as follows:



- Finally, using zero potential concept calculated potential at a point by assuming the point A is at infinity i.e., $r_A = \infty$ then, $V_A = 0$. Therefore, setting, $r_A = \infty$ and $V_A = 0$ in above equation $V_B - V_A = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$, getting $V_B - 0 = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r_B} - \frac{1}{\infty}\right)$ Or, $V_B = \frac{q}{4\pi\varepsilon_0 r_B}$ by showing another concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the electric potential difference and zero potential by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with the electric potential difference and zero potential by showing same concept map providing with illustrations to get final propositions as:
    - Electric potential difference is a scalar quantity.
- Electric potential difference between two points inside electric field can be expressed as $V_{AB} = V_B - V_A = \frac{W_{AB}}{q_0} = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$ in free space.
- The potential at infinite distance from point charge is assumed to be at zero potential.

- The potential at a point can also be calculated by assuming zero potential.
- Finally summarize the concept of electric potential difference between points by showing the same concept map.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
  - ➢ Can you recall and explain the fundamental concept of electric potential difference between points due to a point charge?
  - ➢ How would you describe the significance of electric potential difference in the context of electric fields and point charges?
  - ➢ In what ways does electric potential difference between points differ from electric potential at a point due to point charge?
  - ➢ Can you provide an example from daily life where understanding electric potential difference between charges might be useful?

Assignment and closure

(5 min)

- What is electric potential difference between points inside an electric field?
- Provide an example of a real-world application where the understanding of electric potential difference is crucial.
- Derive a relation of electric potential difference between points in free space.
- What is zero potential? Calculate potential at a point by using zero potential concept.

Episode - Twelve

Topics:

- **Capacitors, Capacitance**
- **Parallel Plate Capacitor**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 593 and 600-601.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 136-137 and 141-142.

Learning Outcome:

By the end of this class, students should be able to:

- Articulate a clear understanding of capacitance as the measure of a capacitor's ability to store electric charge.
- Recognize and describe the key components of a capacitor, including the conductive plates and the dielectric material.
- Comprehend the behavior of capacitors in an electric circuit, specifically their ability to store and release electrical energy.
- Demonstrate the ability to analyze and explain the operation of a parallel plate capacitor, including the role of plate area, separation distance, and dielectric material.
- Apply relevant formulas to calculate the capacitance of a parallel plate capacitor based on its physical characteristics.
- Connect the theoretical concepts of capacitors and capacitance to practical applications in electronic circuits and devices.

- Solve numerical problems involving capacitors, capacitance, and parallel plate capacitors, applying mathematical principles to real-world scenarios.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge or familiarity they have about upcoming topic on capacitors, capacitance, and parallel plate capacitors.
- any previous understanding, they may have regarding capacitance, capacitor components, or the behavior of capacitors in electric circuits.
- any practical applications they might be aware of where capacitors are used, fostering a connection between theoretical knowledge and real-world scenarios.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

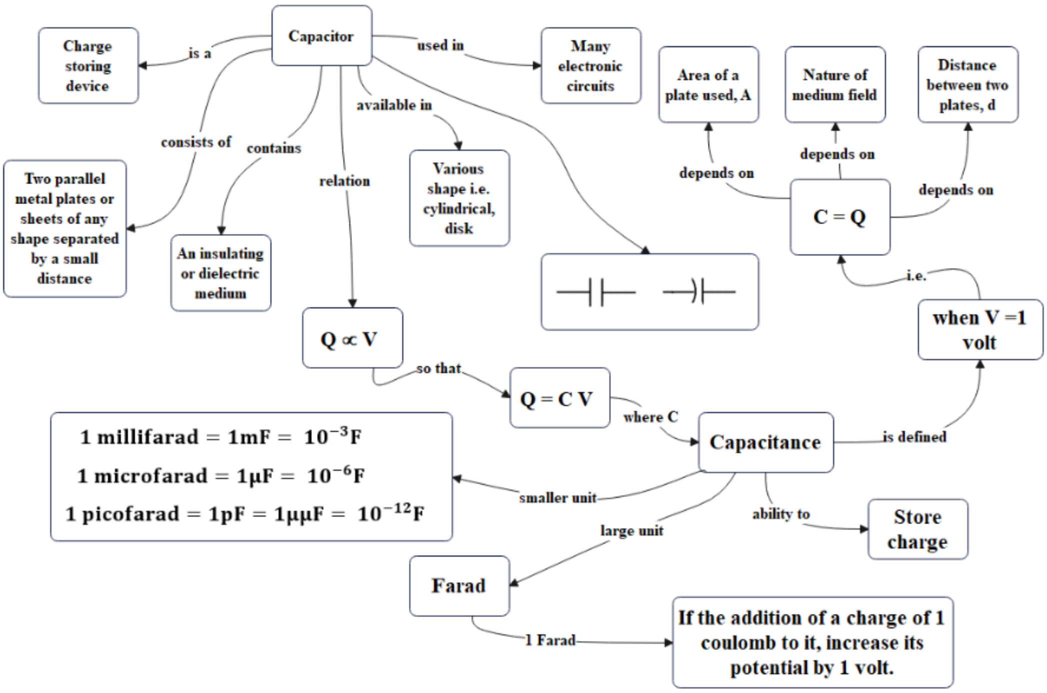
(5 min)

- Present the term capacitors, capacitance, and parallel plate capacitors as an advance organizer.
- Give a brief overview of terms related to capacitors, capacitance, and parallel plate capacitors.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe and define capacitors, and capacitance by presenting concept map as follows:



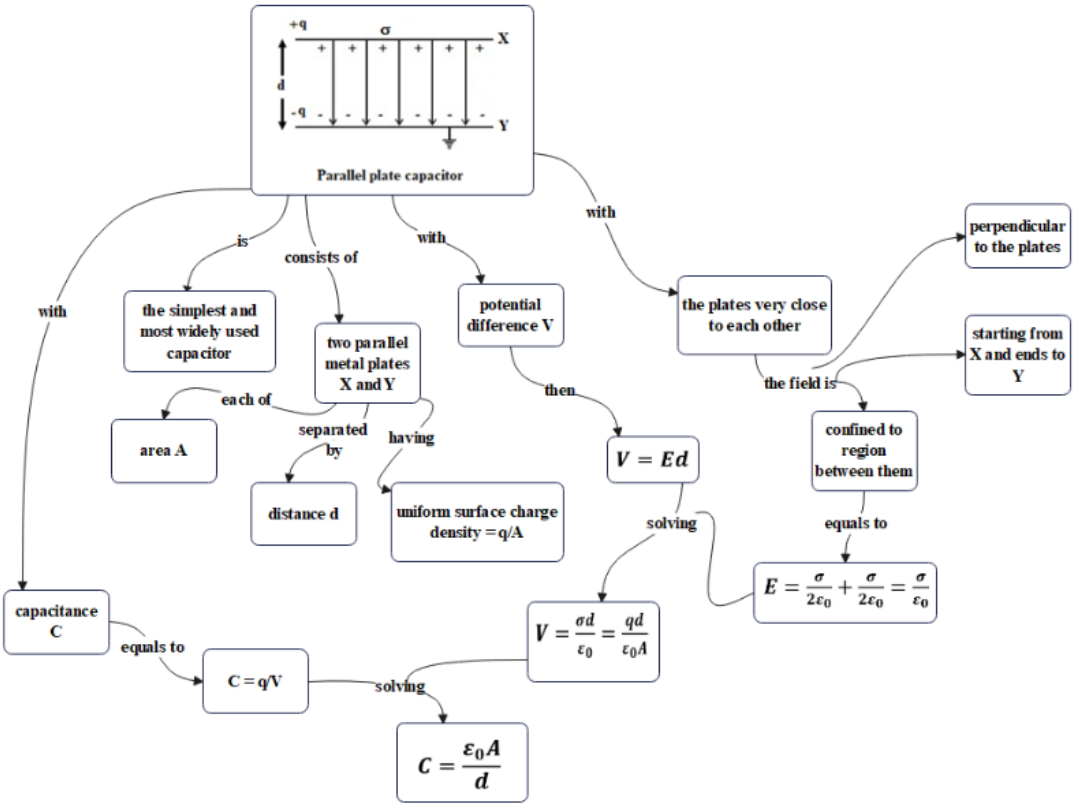
- Defined capacitors by showing the same concept map.
- Discussed the essential components of capacitor.
- Elaborated the relationship between charge developed and potential developed between two plates i.e. $Q \propto V$ by showing in the same concept map.

(5min)

- Presented mathematical expression Q = CV and explained how they are applied to calculate the capacitance of capacitors by showing in the same concept map.
- Worked through examples, illustrating step-by-step involving dielectrics between two plates, significance of capacitors, units and smaller units of capacitors by providing same concept map.

(5 min)

- Describe and define parallel plate capacitors by presenting another concept map as follows:



- Explained the construction of parallel plate capacitor with plate area A separated by distance d with capacitance C and with uniform surface charge density σ = q/A by showing in same concept map.
- Calculated the potential of system of parallel plate capacitor by showing the same concept map.
- Furthermore, the potential is put into the expression C = q/V to get capacitance as

  $C = \frac{\varepsilon_0 A}{d}$ by providing the concept into same concept map.
- Illustrated practical applications of parallel plate capacitor.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of the capacitors, capacitance and parallel plate capacitor by linking with appropriate verbs.

- Also, reconcile integration of all sub concepts related with the capacitors, capacitance and parallel plate capacitor by showing same concept map providing with illustrations to get final propositions as:
  - The capacitor is charge storing device consists of two parallel metallic sheet separated by certain distance.
  - Farad (F) is the greater unit of capacitance whereas milli, micro, and Pico farads are the smallest unit of capacitance.
  - Electric field between the two plates of parallel plate capacitor is E =V/d, and surface charge density σ = q/A.
  - Electric field is always acting perpendicular to the plate and from positive plate to negative plate.
  - Electric field between two plates of capacitor is also expressed as $E = \frac{\sigma}{\varepsilon_0}$.
  - Capacitance of parallel plate capacitor is given by $C = \frac{\varepsilon_0 A}{d}$.
  - Capacitance of any capacitor depends upon its area of each plate, separation distance of plates and nature of material media in between two plates.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
  - ➢ Can you summarize the key concepts we discussed regarding capacitors, capacitance, and parallel plate capacitors?
  - ➢ Reflect on our discussion about capacitor components. Can you recall and describe the main components of a capacitors?

- How would you explain the behavior of capacitors in an electric circuit, particularly in terms of their ability to store energy?

Assignment and closure

(5 min)

- Define capacitance and explain its significance in the context of capacitors. Discuss the role of capacitance in storing electric charge.
- Establish the relation of capacitance of parallel plate capacitors.
- Explore the impact of dielectric materials in the capacitance of a parallel plate capacitor.
- A parallel plate capacitor has square plates of side 5 cm and separated by a distance of 1 mm. (a) Calculate the capacitance of this capacitor. (b) If a 10 V battery is connected to the capacitor, what is the charge stored in any one of the plates?

  (The value of $\varepsilon_o = 8.85 \times 10^{-12}$ Nm^2 C^{-2})
- A parallel plate capacitor filled with mica having $\varepsilon_r = 5$ is connected to a 10 V battery. The area of the parallel plate is 6 m^2 and separation distance is 6 mm.

  (a) Find the capacitance and stored charge.

  (b) After the capacitor is fully charged, the battery is disconnected and the dielectric is removed carefully.

  Calculate the new values of capacitance, stored energy and charge.

Episode - Thirteen

Topics:

- **Isolated spherical capacitor**
- **Co-axial spherical capacitor**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 601-602.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 137-140.

Learning Outcome:

By the end of this class, students should be able to:

- Define and explain the principles of an isolated spherical capacitor, including its components, capacitance formula, and factors influencing capacitance.
- Describe the construction and operation of a concentric coaxial spherical capacitor, emphasizing the role of concentric spheres and the impact on capacitance.
- Demonstrate the ability to calculate capacitance for both isolated spherical capacitors and concentric coaxial spherical capacitors using relevant formulas.
- Relate the concepts learned to real-world applications, understanding how these capacitor configurations are used in practical electronic systems.
- Apply problem-solving skills to solve numerical problems related to the capacitance of isolated spherical capacitors and concentric coaxial spherical capacitors.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge they have about isolated spherical capacitors and concentric coaxial spherical capacitors.
- recall and mention any concepts or terms related to capacitors that they may have encountered in previous classes or experiences.
- any real-life applications or devices where isolated spherical capacitors or concentric coaxial spherical capacitors might be used.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

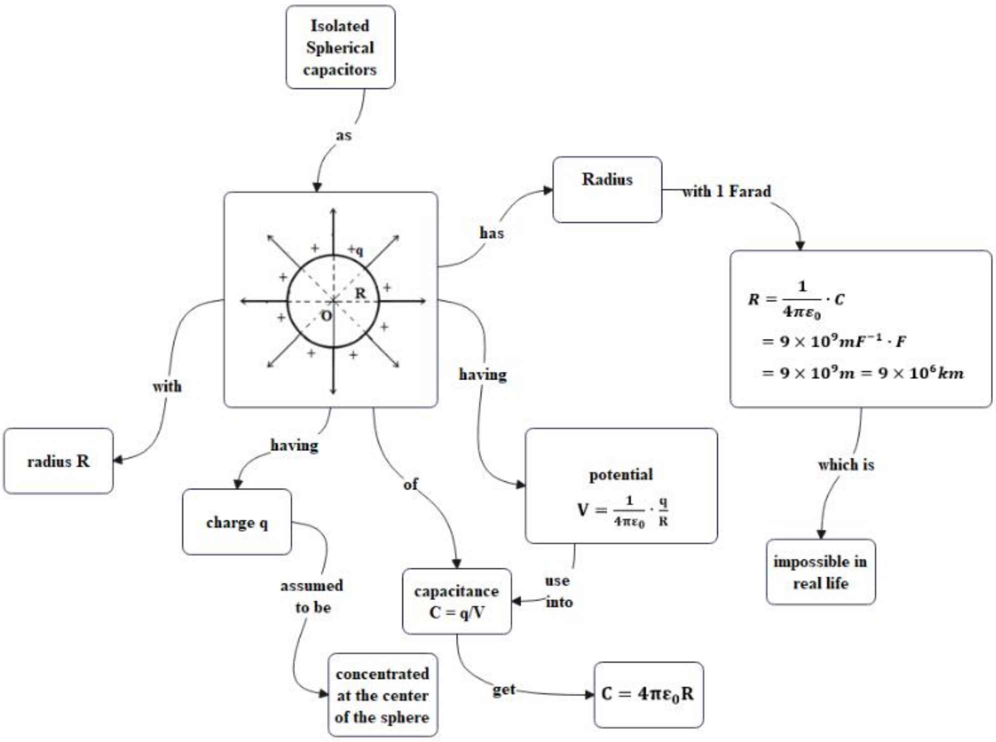
(5 min)

- Present the term isolated spherical capacitors, and coaxial concentric spherical capacitor as an advance organizer.
- Give a brief overview of terms related to isolated spherical capacitors, and coaxial concentric spherical capacitor.

Phase – II: Presentation of learning Task or Material

5 min)

- Describe isolated spherical capacitors by presenting concept map as follows:



- Defined isolated spherical capacitors by showing the same concept map.
- Explained the construction of isolated spherical capacitors with radius R with capacitance C by showing in same concept map.
- Calculated the potential of system of isolated spherical capacitor by showing the same concept map as $V = \frac{q}{4\pi\varepsilon_0 R}$.
- Furthermore, the potential is put into the expression C = q/V to get capacitance as

  $C = 4\pi\varepsilon_0 R$ by providing the concept into same concept map.

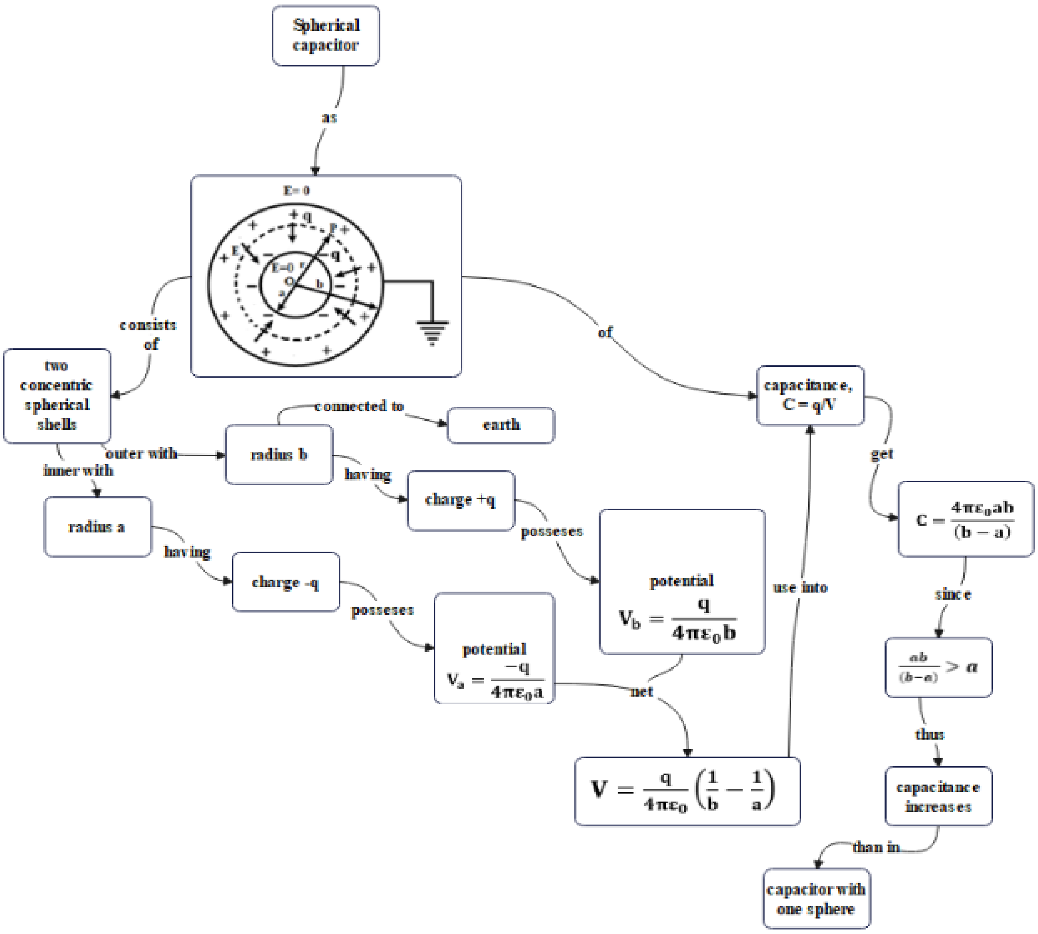
(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of an isolated spherical capacitors by linking with appropriate verbs.

- Also, reconcile integration of all sub concepts related with an isolated spherical capacitor by showing same concept map providing with illustrations to get final propositions as:
  - The capacitor is charge storing device consists of two parallel metallic sheets separated by certain distance.
  - Farad (F) is the greater unit of capacitance whereas milli, micro, and Pico farads are the smallest unit of capacitance.
  - Charge on spherical capacitor is assumed to concentrate at its center.
  - Capacitance of parallel plate capacitor is given by $C = 4\pi\varepsilon_0 R$.
  - Capacitance of an isolated spherical capacitor depends upon its radius and nature of material media in which capacitor is placed.

(5 min)

- Describe and define coaxial concentric spherical capacitor by presenting another concept map as follows:



- Defined coaxial concentric spherical capacitor by showing the same concept map.
- Explained the construction of coaxial concentric spherical capacitor with inner radius a and outer radius b with capacitance C by showing in same concept map.
- Calculated the potential of system of coaxial concentric spherical capacitor by showing the same concept map as $V = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{b} - \frac{1}{a}\right)$.
- Furthermore, the potential is put into the expression C = q/V to get capacitance as

  $C = 4\pi\varepsilon_0 \frac{ab}{(b-a)}$ by providing the concept into same concept map.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of coaxial concentric spherical capacitor by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with coaxial concentric spherical capacitor by showing same concept map providing with illustrations to get final propositions as:
  - The capacitor is charge storing device consists of two parallel metallic sheets separated by certain distance.
  - Farad (F) is the greater unit of capacitance whereas milli, micro, and Pico farads are the smallest unit of capacitance.
  - Coaxial concentric spherical capacitor consists of two coaxial and concentric spherical shells.
  - Capacitance of parallel plate capacitor is given by $C = 4\pi\varepsilon_0 C = 4\pi\varepsilon_0 \frac{ab}{(b-a)}$.
  - The capacitance of coaxial concentric spherical capacitor is greater than isolated spherical capacitor
  - Capacitance of coaxial concentric spherical capacitor depends upon its radii and nature of material media in which capacitor is placed.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
  - ➢ Can you explain the key components of an isolated spherical capacitor and how they contribute to its capacitance?

- What factors influence the capacitance of an isolated spherical capacitor, and how do they affect its performance?
- Can you provide examples of real-world applications where isolated spherical capacitors and coaxial concentric spherical capacitors are commonly used?
- Can you summarize the key concepts we discussed regarding Isolated spherical capacitors, and Coaxial concentric spherical capacitor?
- Reflect on our discussion about capacitor components. Can you recall and describe the main components of a capacitors?

Assignment and closure

(5 min)

- Derive the relation of capacitance of an isolated spherical capacitor.
- How does the capacitance of a concentric coaxial spherical capacitor differ from that of an isolated spherical capacitor?
- Calculate the capacitance of coaxial concentric spherical capacitor.
- Why the capacitance of coaxial concentric spherical capacitor is greater than isolated spherical capacitor?

Episode – Fourteen

Topics:

- **Dielectrics**
- **Polarization of dielectrics**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 602-604.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 144-147.

Learning Outcome:

By the end of this class, students should be able to:

- Articulate a clear understanding of what dielectrics are and how they differ from conductors and insulators.
- Grasp the concept of polarization as it relates to dielectrics, recognizing how the arrangement of charges within a dielectric material change under the influence of an external electric field.
- Recognize common materials used as dielectrics and understand their properties that make them suitable for this purpose.
- Relate theoretical knowledge to real-world applications, such as the use of dielectrics in electronic components and devices.
- Explore different mechanisms of polarization in dielectric materials, including electronic polarization, ionic polarization, and orientation polarization.

- Solve problems related to dielectrics and polarization, including calculating the capacitance of capacitors with dielectric materials and analyzing the impact of dielectric properties on the overall performance of electronic circuits.
- Engage in discussions about the role of dielectrics in electrical engineering and share insights on how polarization contributes to the functionality of various electronic systems.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge or experiences they might have regarding dielectrics and the polarization of dielectric materials.
- the definition of dielectrics and how they differed from conductors and insulators.
- any experiences or real-world applications they could recall involving dielectric materials.
- targeted questions to prompt students' recall and engagement.
- any misconceptions and provided brief explanations as needed.
- if students were familiar with the concept of polarization in the context of dielectrics.
- any practical applications they may be aware of that involve coaxial cylindrical capacitors.
- any insights or examples related to the properties and applications of dielectrics.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

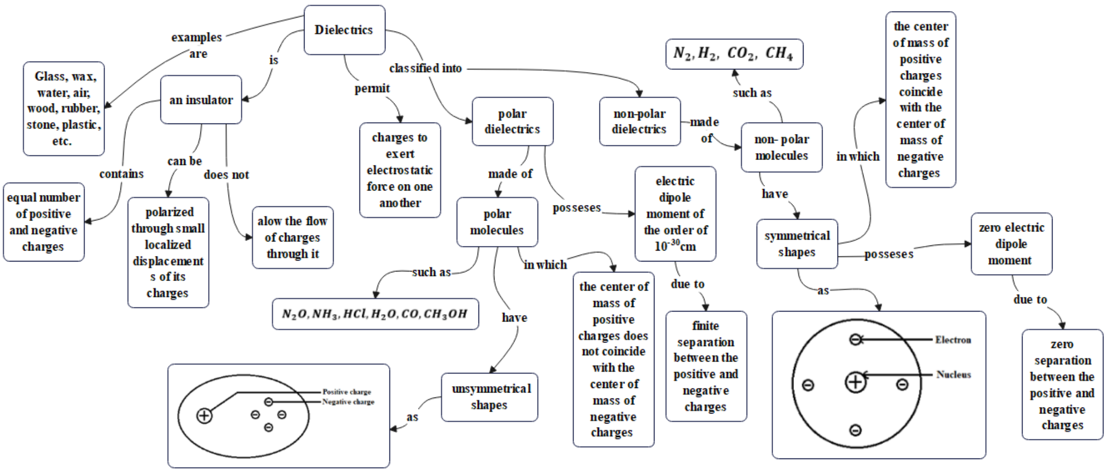
(5 min)

- Present the term dielectrics and polarization of dielectrics as an advance organizer.
- Give a brief overview of terms related to dielectrics and polarization of dielectrics.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe dielectrics by presenting concept map as follows:



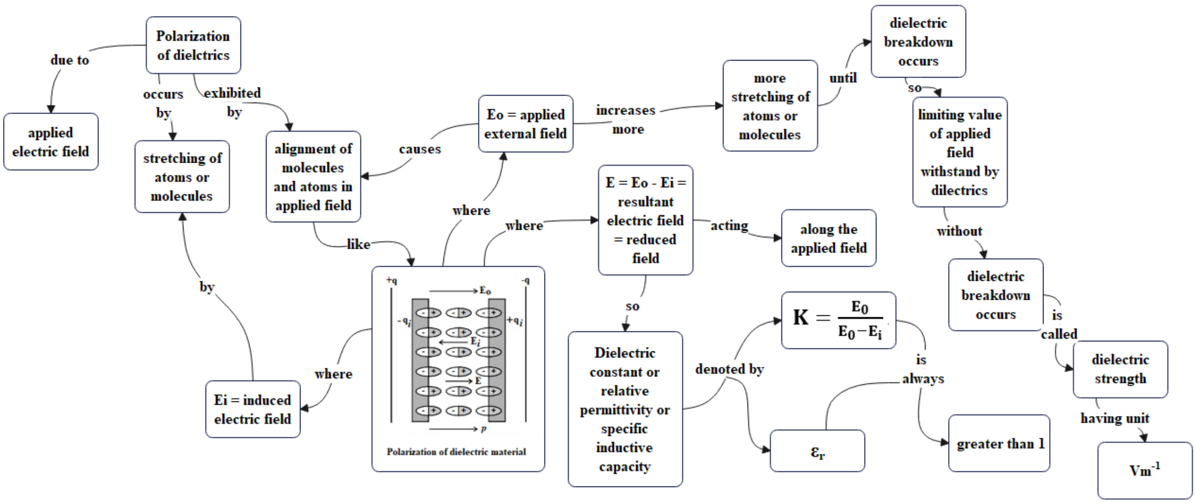
- Defined dielectric constant and explained its types by showing the same concept map.
- Explained the two types of dielectrics with their examples and properties by showing in same concept map.
- Elaborated the concept of dipole moment of polar and non-polar dielectrics.
- Furthermore, the figure of two types of dielectric molecules is drawn by providing the concept into same concept map.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of dielectrics by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with dielectrics by showing same concept map providing with illustrations to get final propositions as:
    - The dielectric is an insulator consists of equal number of positive and negative charges.
    - Glass, wax, water, air, wood, rubber, stone, plastic etc. are good examples of dielectrics.
    - Dielectrics are classified into polar and non-polar dielectrics.
    - Charges are symmetrically distributed in non-polar dielectrics.
    - Non-polar dielectrics are made of non-polar molecules such as N_2, H_2, $CO_2,\ CH_4$.
    - Charges are asymmetrically distributed in polar dielectrics.
    - Polar dielectrics are made of polar molecules such as $N_2O, NH_3, HCl, H_2O, CO, CH_3OH$.

(5 min)

- Describe and define polarization of dielectrics by presenting another concept map as follows:



- Defined polarization of dielectrics by showing the same concept map.
- Explained the mechanism and process of polarization in both cases of polar and non-polar dielectrics by showing in same concept map.
- Described the concept of induced charge, induced electric field E_i and reduction of electric field due the polarization of dielectrics.
- Furthermore, defined the dielectric constant in terms of the reduced field and applied fields as $K = \frac{E_0}{E_0 - E_i}$ by providing the concept into same concept map.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of polarization of dielectrics by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with polarization of dielectrics by showing same concept map providing with illustrations to get final propositions as:
  - The polarization of dielectrics occurs due to the application of external applied field by the stretching of atoms or molecules of dielectrics.
  - The polarization of dielectrics exhibited by the alignment of atoms or molecules along the direction of applied field.

- Dielectric constant K is the ratio of applied field to the reduced field as given by $K = \frac{E_0}{E_0 - E_i}$.
- The maximum electric field that can be withstand by dielectrics without its dielectric breakdown is called dielectric strength.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
    - ➢ Can you summarize the key characteristics and components of a dielectrics?
    - ➢ Can you define what dielectrics are and distinguish them from conductors and insulators?
    - ➢ Describe the mechanisms of polarization discussed in the class.
    - ➢ Explain how mechanism contributes to the polarization of dielectric materials.
    - ➢ Name and discuss examples of common materials used as dielectrics.
    - ➢ Explain why these materials are suitable for use as dielectrics.
    - ➢ How do the properties of dielectric materials impact the capacitance of capacitors?
    - ➢ Provide examples of real-world applications where dielectrics play a crucial role.

Assignment and closure

(5 min)

- Define dielectrics and distinguish them from conductors and insulators?
- Explain different types of dielectrics with illustrations and their properties.

- Describe the mechanisms of polarization. Define dielectric constant.
- Explain how mechanism contributes to the polarization of dielectric materials.
- Name and discuss examples of common materials used as dielectrics.
- How do the properties of dielectric materials impact the capacitance of capacitors?
- Provide examples of real-world applications where dielectrics play a crucial role.

Episode – Fifteen

Topics:

- **Energy stored in capacitor and energy density**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 608-610.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 153-154.

Learning Outcome:

By the end of this class, students should be able to:

- Clearly articulate the concept of energy stored in a capacitor.
- Demonstrate the ability to calculate the energy stored in a capacitor using the appropriate formula, considering the capacitance and voltage across the capacitor.
- Explain the process of charging a capacitor and how energy is transferred and stored during this process.
- Connect the amount of energy stored in a capacitor to the capacitance and voltage, understanding how these parameters influence the overall energy storage capacity.
- Define and comprehend the concept of energy density, particularly in the context of capacitors, and discuss its significance.

- Calculate the energy density in a capacitor, considering the volume occupied by the dielectric material and understanding the relationship between energy density and stored energy.
- Relate the concepts of energy stored and energy density to practical applications in electronic devices and circuits, understanding their relevance in engineering design.
- Solve numerical problems involving energy stored in capacitors and energy density, applying mathematical principles to real-world scenarios.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge they have about energy stored and energy density in capacitors.
- recall and mention any concepts or terms related to capacitors that they may have encountered in previous classes or experiences.
- any real-life applications or devices where the concept of energy stored in capacitors might be used.
- prompt them to explain the relationship between the charge on a capacitor, voltage, and the energy stored.
- check if they have encountered any challenges or misconceptions related to the concept of energy stored in capacitors in their previous studies.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

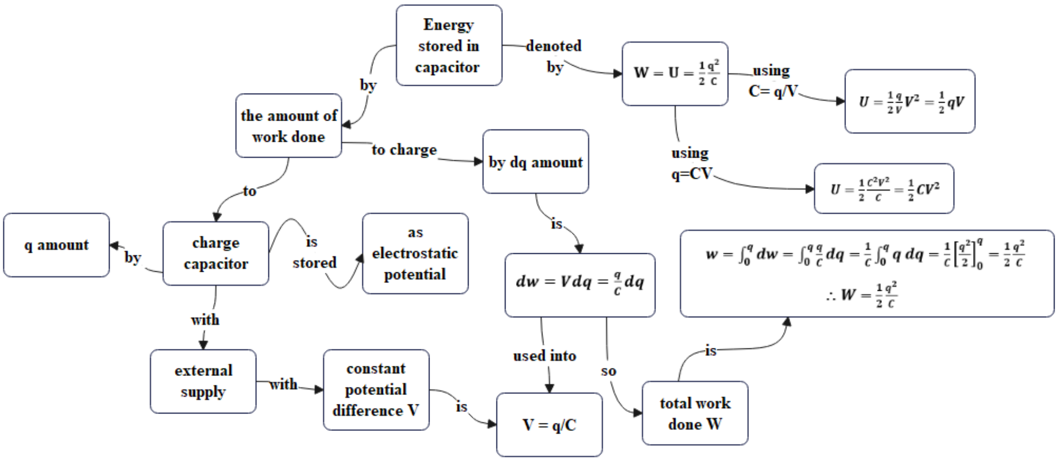
(5 min)

- Present the term energy stored in capacitor and energy density as an advance organizer.
- Give a brief overview of terms related to energy stored in capacitor and energy density.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe energy stored in capacitor by presenting concept map as follows:



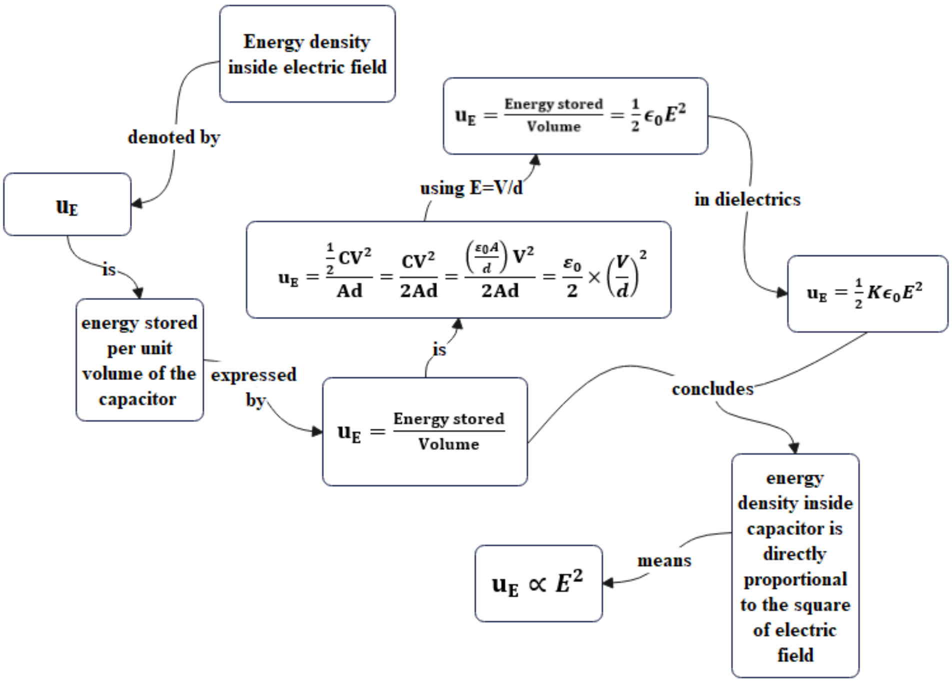
- Defined energy stored in capacitor by showing the same concept map.
- Explained the energy density as an amount of work done in charging the capacitor by external source is stored as in the form of electrostatic potential energy by showing in same concept map.
- Calculated the small energy stored dw inside a capacitor by showing the same concept map as $dw = Vdq = \frac{q}{C}dq$.
- Furthermore, the total energy stored was calculated by integrating from charging 0 to q to get energy stored as $w = \int_0^q dw = \int_0^q \frac{q}{C}dq = \frac{1}{C}\int_0^q q\,dq = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^q = \frac{1}{2}\frac{q^2}{C}$ providing the concept into same concept map.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of an energy stored inside capacitors by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with an energy stored inside capacitors by showing same concept map providing with illustrations to get final propositions as:
  - The energy stored inside capacitors as total amount of work done in charging the capacitor as in the form of electrostatic potential energy.
  - Energy stored is expressed by notation U as $U = \frac{1}{2}CV^2 = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2}qV$.

(5 min)

- Describe and define energy density in capacitor by presenting another concept map as follows:



- Defined energy density inside a capacitor by showing the same concept map.

- Explained the energy stored is the energy stored per unit volume of the capacitor and expressed by $\mathrm{u_E} = \frac{\text{Energy stored}}{\text{Volume}} = \frac{\mathrm{U}}{\mathrm{V}}$ by showing in same concept map.
- Calculated the energy stored inside a capacitor by showing the same concept map as

$$\mathrm{u_E} = \frac{\text{Energy stored}}{\text{Volume}} = \frac{\frac{1}{2}\mathrm{CV}^2}{\mathrm{Ad}} = \frac{\mathrm{CV}^2}{2\mathrm{Ad}} = \frac{\left(\frac{\varepsilon_0 A}{d}\right)\mathrm{V}^2}{2\mathrm{Ad}} = \frac{\varepsilon_0}{2} \times \left(\frac{V}{d}\right)^2 = \frac{1}{2}\epsilon_0 E^2$$

- Furthermore, the energy stored inside capacitor in the presence of dielectric can be expressed by $\mathrm{u_E} = \frac{1}{2}K\epsilon_0 E^2$ by showing into the same concept map.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of energy density inside a capacitor by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with energy density inside capacitor by showing same concept map providing with illustrations to get final propositions as:
  - The energy density can be denoted by $\mathrm{u_E}$.
  - The energy density inside a capacitor is the energy stored per unit volume of capacitor.
  - The energy density inside a capacitor is also called as energy density inside an electric field and directly proportional to the square of an electric field as $\mathrm{u_E} \propto E^2$.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
  - ➢ Can you explain the relationship between the charge on a capacitor, voltage, and the energy stored in the capacitor?
  - ➢ What formula is used to calculate the energy stored in a capacitor, and how does it incorporate relevant parameters?
  - ➢ Have you encountered any challenges or limitations related to energy storage in capacitors in practical scenarios?
  - ➢ Can you think of any practical applications or devices where understanding the energy stored in capacitors is crucial?
  - ➢ Define the concept of energy density as it applies to capacitors.
  - ➢ How is energy related to the physical characteristics of a capacitor?

Assignment and closure

(5 min)

- Define and derive the relation of energy stored inside capacitor in terms of charge, capacitance, and voltage.
- Explain, in your own words, how energy is stored in a capacitor. What role does the electric field play in this process?
- Define energy density in capacitor and show that energy density is directly proportional to the square of electric field.
- A capacitor of capacitance 25 μF is charged to a potential of 500V. calculate the energy stored in the capacitor.

Episode – Sixteen

Topics: Combination of capacitor

- **Series combination**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 607-608.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 150-151.

Learning Outcome:

By the end of this class, students should be able to:

- Clearly define and explain the concept of the combination of capacitors in series.
- Understand the basic principles governing the behavior of capacitors connected in series.
- Identify and analyze scenarios where capacitors are connected in series within an electrical circuit.
- Recognize the characteristic features of series capacitor configurations.
- Demonstrate the ability to calculate the equivalent capacitance for capacitors connected in series.
- Apply relevant formulas and understand the relationship between individual capacitances and the equivalent capacitance in series.
- Analyze the distribution of voltage across capacitors in a series combination.
- Understand how the potential difference is shared among each capacitor connected in series configuration.

- Apply problem-solving skills to solve numerical problems related to series combinations of capacitors.
- Relate to practical applications.
- Solve real-world problems.
- Participate in collaborative discussions.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any previous exposure or familiarity with the concept of combining capacitors, particularly in a series combination.
- if students have encountered scenarios involving capacitors connected in series in their prior studies.
- any specific questions, challenges, or real-world observations related to series combinations of capacitors.
- their understanding of how capacitors behave when connected in series.
- targeted questions to prompt students' recall and engagement.
- any misconceptions and provided brief explanations as needed.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

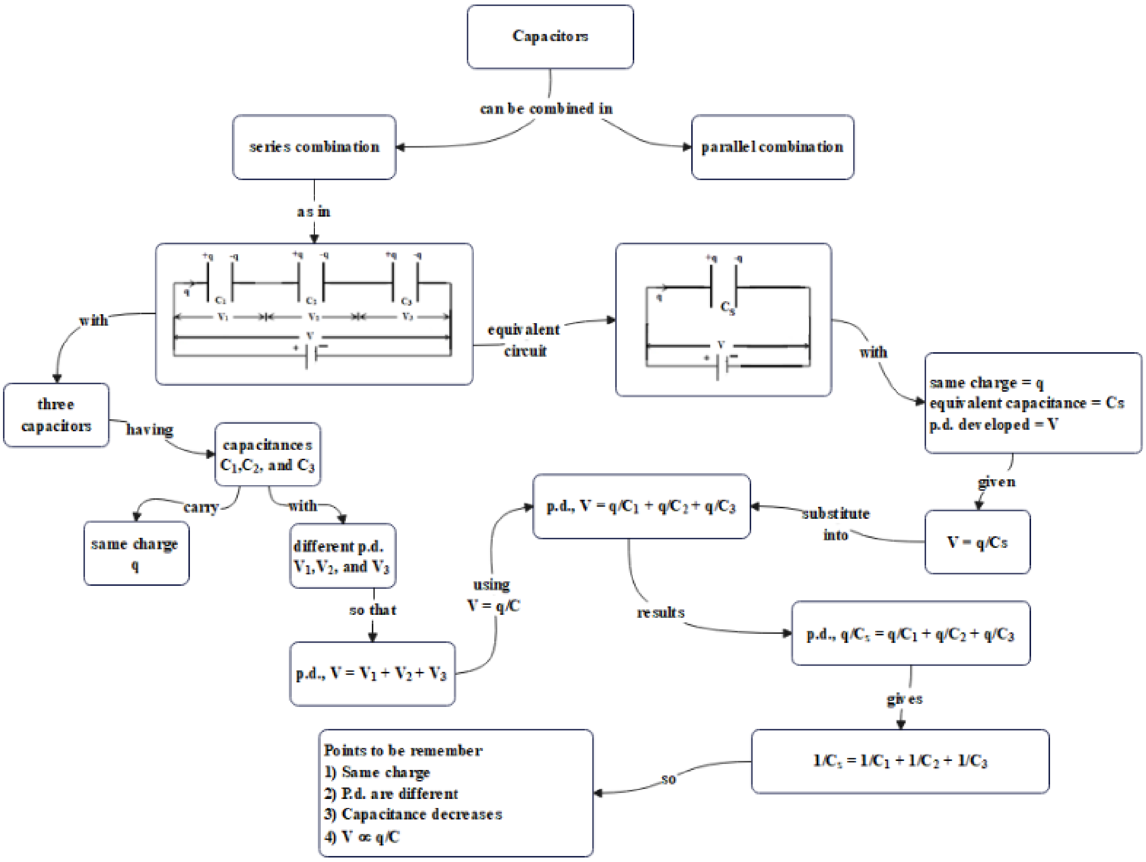
(5 min)

- Present the term series combination of capacitors as an advance organizer.
- Give a brief overview of terms related to series combination of capacitors.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe series combination of capacitors by presenting concept map as follows:



- Discussed the combination of capacitors and its types by showing the same concept map.
- Elaborated the fundamental principles governing the behavior of capacitors in series combination of capacitors.
- Explained the series combination of capacitors by showing in same concept map.
- Identified and explained the characteristic features of series capacitor configurations.
- Encouraged students to contribute additional details and insights to the concept map, linking principles and characteristics.

(5min)

- Explained the charge distributions are same in all capacitors connected in series combination by showing in same concept map.
- Discussed how the potential differences are distributed across capacitors in a series combination.
- Considered an example by taking three capacitors with capacitances C_1, C_2, and C_3 having potential differences V_1, V_2, and V_3 respectively with same charge q by showing same concept map.
- Taught the method to calculate the equivalent capacitance for capacitors connected in series by showing the same concept map.
- Explained the concept map to include formulas q = CV, calculations, and the relationship between individual capacitances and the equivalent capacitance.
- Finally calculated the potential difference for this case by showing same concept map as

$$V = V_1 + V_2 + V_3$$

$$V = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3} = q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

(5 min)

- Took the equivalent capacitor with capacitance C_{eq} in which same charge q to develop potential difference by V amount by showing same concept map.
- Calculated the potential difference V for this case by showing the same concept map as $V = \frac{q}{C_{eq}}$.
- Furthermore, the equivalent capacitance can be calculated by equating the both cases so as to get by showing into same concept map.as

$$\frac{q}{C_s} = q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$\therefore \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}$$

- Finally, concluded the general expression of equivalent capacitance for n – number of capacitors as

$$\therefore \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}$$

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of series combination of capacitors by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with series combination of capacitors by showing same concept map providing with illustrations to get final propositions as:

- Same charges are distributed in all capacitors connected in series configuration.
- Different potential differences are developed across capacitors in series combination.
- In series combination the reciprocal of equivalent capacitance is given by the sum of reciprocals of individual capacitance connected.
- Equivalent capacitance decreases in series combination.
- Potential difference developed in each capacitor is inversely proportional to their capacitances as $V \propto \frac{1}{C}$ with constant charge distribution.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
    - ➢ Can you articulate the key principles governing capacitors in series? How do they differ from individual capacitors?

  - Recall and explain the formula for calculating the equivalent capacitance of capacitors in series.
  - Discuss the distribution of charge and voltage across each capacitor in a series combination.
  - Reflect on the practical applications discussed in class where series capacitor configurations are commonly used. Can you think of additional real-world scenarios?
  - Consider the concept map I presented during the class, what connections or insights did you find most helpful in understanding series combination of capacitors?
  - Share any challenges or uncertainties you have regarding the topic. Are there specific aspects that you would like further clarification on?
  - Would anyone like to share a particular aspect of today's lesson that stood out to them or that they found particularly interesting?

Assignment and closure

(5 min)

- Define the concept of equivalent capacitance in a series combination of capacitors.
- Explain the fundamental principles that govern the behavior of capacitors when connected in series.
- Calculate the capacitance of a combination of three capacitors of capacitances 8, 12, and 24 μF, when they are connected in series combination. Find the charge on each plate in the series arrangement, if the potential difference across the system is 100 volts.

- Discuss how the obtained equivalent capacitance affects the overall energy storage capacity of the circuit.
- Explain the advantages and disadvantages of employing capacitors in series in the identified application.
- Evaluate the impact of changing the capacitance of one capacitor in a series configuration on the overall circuit.

Episode – Seventeen

Topics: Effects of dielectric

- **Capacitance of a capacitor**
- **Electric field intensity**
- **Potential difference between the plates**
- **Energy stored inside the capacitor**

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 602-604.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 147-149.

Learning Outcome:

By the end of this class, students should be able to:

- understand the impact of dielectric material on the capacitance of a capacitor.
- calculate and predict changes in capacitance when a dielectric material is introduced.
- analyze how dielectric materials influence electric field intensity within a capacitor.
- calculate electric field intensity considering the presence of dielectric material.
- investigate the effect of dielectric medium on the potential difference across capacitor plates.
- calculate and predict changes in potential difference when dielectric mediums are inserted.

- comprehend how the presence of dielectric material affects the energy stored within a capacitor.
- calculate and compare the energy stored with and without dielectric material.
- explain the role of dielectrics in enhancing and reducing energy storage in capacitors.
- Solve numerical problems involving effects of dielectric medium on capacitance, electric field intensity, potential differences, and energy stored.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge they have about effects of dielectric medium on capacitances of capacitors, electric field developed in capacitors, potential differences on capacitors, and energy stored in capacitors.
- recall and mention any concepts or terms related to capacitors that they may have encountered in previous classes or experiences.
- any real-life applications or devices where the concept of effects of dielectrics on capacitors and its related variables.
- prompt them to explain the relationship between the capacitances, electric field intensity, potential differences, and energy stored with and without dielectric materials.
- check if they have encountered any challenges or misconceptions related to the concept of effects of dielectrics in their previous studies.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

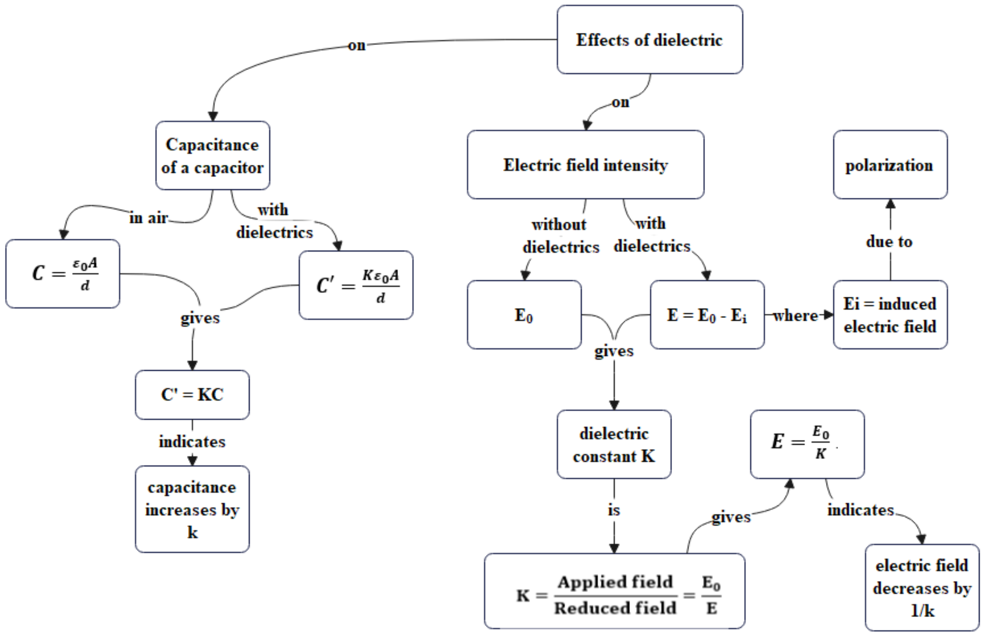
(5 min)

- Present the term effects of dielectric medium on capacitances of capacitors, and electric field intensity in capacitor as an advance organizer.
- Give a brief overview of terms related to dielectrics and its effect on capacitance and electric field intensity in capacitor.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe effects of dielectric on capacitance and electric field intensity in capacitor by presenting concept map as follows:



- Described the capacitance of capacitor in air and with dielectrics as $C = \frac{\varepsilon_0 A}{d}$ and $C' = \frac{K\varepsilon_0 A}{d}$ by showing the same concept map.
- Explained, the calculation of the new relation by using above both relations as $C' = KC$.

- Furthermore, concluded the result as the capacitance of a capacitor increases K times due to introduction of dielectric medium by showing in same concept map.
- Explained as if E_0 be the applied electric field intensity in absence of dielectric and E be the electric field intensity in presence of dielectric medium by showing same concept map so that

$$E = E_0 - E_i$$

- Described the concept of E_i as induced electric field due to polarization of dielectrics.
- Furthermore, elaborated dielectric constant K as

$$K = \frac{Applied\ field}{Reduced\ field} = \frac{E_0}{E}$$

- Explained, the calculation of the new relation by using above both relations as

$$E = \frac{E_0}{K}$$

- Furthermore, concluded that the effect of introduction of dielectric between the plates of a capacitor is to weaken or decrease the electric field across the plates by a factor $\frac{1}{K}$.

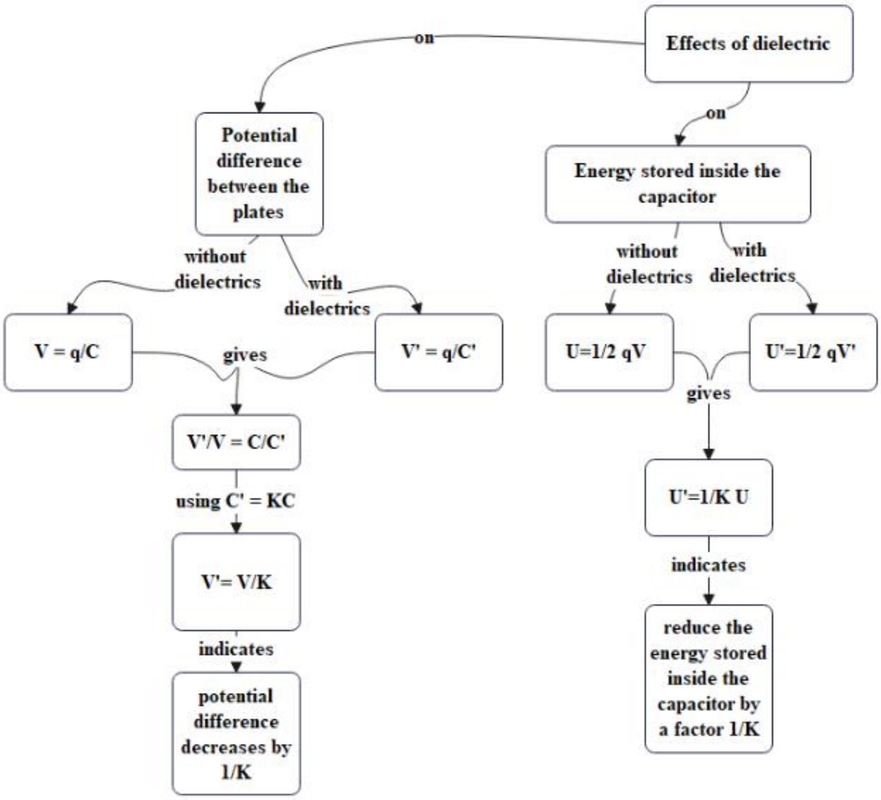
(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of an effect of dielectrics on capacitance and electric field intensity inside capacitors by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with an effect of dielectrics on capacitance and electric field intensity by showing same concept map providing with illustrations to get final propositions as:
    - The capacitance of a capacitor increases K times due to introduction of dielectric medium as $C' = KC$.

- The effect of introduction of dielectric between the plates of a capacitor is to weaken or decrease the electric field across the plates by a factor $\frac{1}{K}$.

(5 min)

- Describe effects of dielectric on potential difference and energy stored in capacitor by presenting concept map as follows:



- Described the capacitance of capacitor in air and with dielectrics as $C = \frac{q}{V}$and $C' = \frac{q}{V'}$ by showing the same concept map. Elaborated V and V' potential differences developed without and with dielectrics in capacitator.
- Explained, the calculation of the new relation by using above both relations as

$$\frac{C}{C'} = \frac{V'}{V}$$

In addition to, described by using the relation $C' = KC$ in above relation to get

$$V' = \frac{1}{K}V$$

- Furthermore, concluded that the effect of introduction of dielectric between the plates of a capacitor is to reduce the potential difference between the plates by a factor $\frac{1}{K}$.
- Described the energy stored in capacitor with air and with dielectrics as $U = \frac{1}{2}qV$ and $U' = \frac{1}{2}qV'$ by showing the same concept map.
- Explained, the calculation of the new relation by using above both relations as

$$\frac{U\prime}{U} = \frac{V\prime}{V} = \frac{1}{K}$$

$$\therefore U' = \frac{1}{K}U$$

- Furthermore, concluded that the effect of dielectric is to reduce the energy stored inside the capacitor by a factor $\frac{1}{K}$.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of an effect of dielectrics on potential differences and energy stored inside capacitors by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with an effect of dielectrics on potential differences and energy stored inside capacitors by showing same concept map providing with illustrations to get final propositions as:

- The effect of introduction of dielectric between the plates of a capacitor is to reduce the potential difference between the plates by a factor $\frac{1}{K}$.
- The effect of dielectric is to reduce the energy stored inside the capacitor by a factor $\frac{1}{K}$.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
    - What key factors influence the capacitance of a capacitor, and how does the introduction of a dielectric impact these factors?
    - Explain the role of electric field intensity in capacitors and how the presence of a dielectric medium affects it.
    - Describe the relationship between the potential difference across the plates of a capacitor and the presence of a dielectric medium.
    - Discuss the concept of energy stored in a capacitor and how it is influenced by the introduction of dielectric materials.

Assignment and closure

(5 min)

- Write down the capacitance of a capacitor with and without a dielectric. Discuss how the introduction of dielectric can enhance the capacitance of a capacitor.
- Illustrate the changes in electric field intensity within the capacitor with and without the dielectric using diagrams.
- Investigate how the potential difference between the plates of a capacitor is affected by the presence of dielectric material. Provide a detailed explanation and use mathematical expressions to support your analysis.
- Reflect on the concept of energy stored inside a capacitor and how it is influenced by the introduction of a dielectric.
- An air capacitor is given a charge of 2 μC raising its potential to 200V. if on inserting a dielectric medium, its potential falls to 50V. what is the dielectric constant of the medium?

Episode – Eighteen

Topics: Lightning conductor

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 611-613.

Learning Outcome:

By the end of this class, students should be able to:

- explain the primary purpose of a lightning conductor and its role in protecting structures and occupants from lightning strikes.
- describe the fundamental working principle of a lightning conductor.
- understand the ionization process that occurs during a lightning strike and explain how the lightning conductor aids in preventing damage by facilitating a controlled path for the electric discharge.
- discuss the materials commonly used in the construction of lightning conductors.
- communicate effectively about the principles and construction of lightning conductors.
- relate to practical applications.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- if they have ever experienced or witnessed a lightning strike.

- their any personal experiences or observations related to lightning and its impact.
- their familiarity with the concept of lightning conductors in previous classes or readings.
- safety measures students may have been taught or are aware of during thunderstorms.
- their perceptions or misconceptions about lighting conductors.
- real-world applications of lightning conductors.
- if students are aware of any historical events or figures related to the development and implementation of lightning conductors.
- targeted questions to prompt students' recall and engagement.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

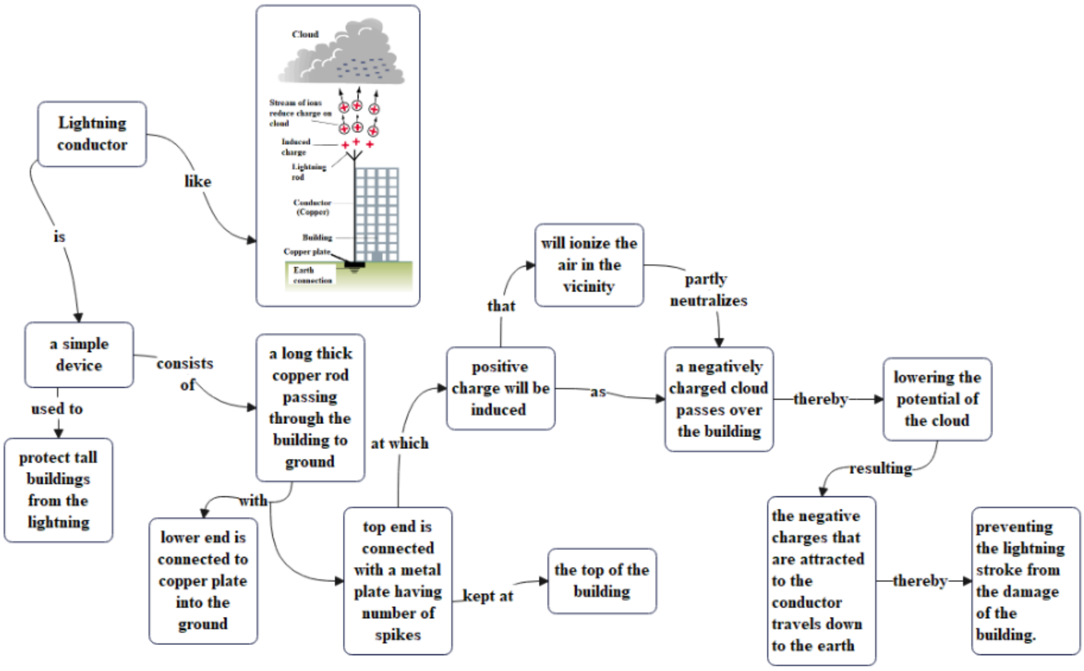
(5 min)

- Present the term lightning conductor as an advance organizer.
- Give a brief overview of terms related to lightning conductor.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe lightning conductor by presenting concept map as follows:



- Described the lightning conductor as a simple device used to protect tall buildings from the lightning.
- Also, explained the construction of lightning conductor by showing the same concept map.

(5 min)

- Furthermore, elaborated by showing to the same concept map as lightning conductor consists of a long thick copper rod passing through the building to ground. The lower end of the rod is connected to a copper plate buried deeply into the ground.
- In addition, described a metal plate with number of spikes is connected to the top end of the copper rod and kept at the top of the building.

(5 min)

- Furthermore, explained the process of ionization of cloud over the lighting conductor by showing the same concept map as when a negatively charged cloud passes over the building, positive charge will be induced on the pointed conductor. The positively charged sharp points will ionize the air in the vicinity.

This will partly neutralize the negative charge of the cloud, thereby lowering the potential of the cloud.

- Moreover, the negative charges that are attracted to the conductor travels down to the earth. Thereby preventing the lightning stroke from the damage of the building.
- Finally, concluded the process of lightning and prevention of the lightning stroke from the damage of the building by showing in same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of lightning conductor by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with lightning rod by showing same concept map providing with illustrations to get final propositions as:

- Lightning rod is the simplest device used to protect tall building from lightning.
- Top end of lightning rod with metal spikes are placed at the top of the building whereas lower part is buried into the ground passing through building.
- As earth is taken at negative potential the positive charges are induced t the top of the lightning conductor.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
  - ➢ What is the primary purpose of a lightning conductor, and how does it achieve its intended goal in protecting structures from lightning strikes?

- Can you describe the fundamental working principle of a lightning conductor?
- Identify and explain the key components of a lightning conductor system.
- What is the material commonly used for the construction of lightning conductors?
- Explain the ionization process that occurs during a lightning strike.
- Would anyone like to share a particular aspect of today's lesson that stood out to them or that they found particularly interesting?

Assignment and closure

(5 min)

- Explain the fundamental principles behind the operation of lightning conductor.
- Discuss the importance of material selection in the construction of lightning conductors.
- Examine the ionization process that occurs during a lightning strike and its role in facilitating a controlled discharge.
- How does the lightning conductor manage the discharge of electrical energy?

Episode – Nineteen

Topics: Uses of static electric field

- **The Electrostatic precipitator**

Time: 45 minutes

Pre-class:

Reading material:

- UK Essays. (November 2018). Practical Applications of Electrostatics. Retrieved from https://www.ukessays.com/essays/engineering/applications-of-electrostatics-analysis-engineering-essay.php?vref=1

Learning Outcome:

By the end of this class, students should be able to:

- name several real-world applications of the study of electrostatics.
- explain the fundamental principles of an electrostatic precipitator, including the role of static electric fields in the separation of particles from a gas stream.
- identify and describe the key components of an electrostatic precipitator.
- explore real-world applications of electrostatic precipitators in various industries.
- clearly communicate the principles and applications of static electric fields in written or verbal form.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- any prior knowledge they have about the instances where static electricity played a role in a practical application.

- the effects of static electricity, such as the clinging of clothes in a dryer or the cracking sound when rubbing certain materials together.
- any practical applications or devices where have you encountered or think this electrostatic precipitator might be used.
- the practical implications of electrostatic precipitator.
- if they have encountered any challenges or misconceptions related to the practical aspects of electrostatic precipitator.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

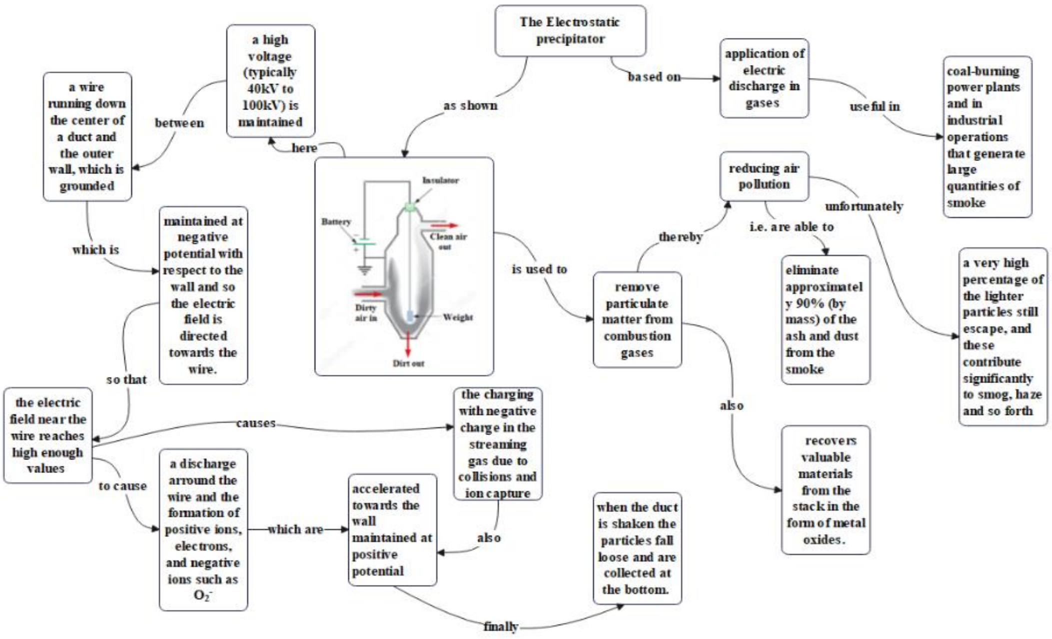
(5 min)

- Present the term electrostatic precipitator as an advance organizer.
- Give a brief overview of the term electrostatic precipitator.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe electrostatic precipitator by presenting concept map as follows:



- Described the constructions of electrostatic precipitator by showing the same concept map.
- Explained, the real visualization of electrostatic precipitator with name of its all parts can be done by showing the same concept map.

(5 min)

- Furthermore, elaborated by showing to the same concept map as a high voltage (typically 40Kv to 100Kv) is maintained between a wire running down the center of a duct and the outer wall, which is grounded.
- Also, the outer wall, which is grounded. The wire is maintained at negative potential with respect to the wall and so the electric field is directed towards the wire.
- In addition, explained the working of electrostatic precipitator by presenting in same concept map as the electric field near the wire reaches high enough values to cause a discharge arround the wire and the formation of positive ions, electrons, and negative ions such as O_2^-. As the electrons and negative ions are accelerated towards the outer wall by the nonuniform electric field, the dirt particles in the streaming gas becomes charged by collisions and ion capture. Since most of the charged dirt particles are negative, they are also drawn to the outer wall by the electric field. When the duct is shaken the particles fall loose and are collected at the bottom.

(5 min)

- Furthermore, explained the application and usefulness of electrostatic precipitator by showing in same concept map as follows:
  - Electrostatic precipitator is used to remove particulate matter from combustion gases, thereby reducing air pollution. It is especially useful in

  coal-burning power plants and in industrial operations that generate large quantities of smoke.
  - In addition to reducing the amount of harmful gases and particulate matter in the atmosphere, the electrostatic precipitator also recovers valuable materials from the stack in the form of metal oxides.

- Finally, concluded the construction and usefulness of electrostatic precipitator to remove particulate matter from atmosphere by showing in same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of electrostatic precipitator by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with precipitator by showing same concept map providing with illustrations to get final propositions as:
- Electrostatic precipitator is used to remove particulate matter from combustion gases, thereby reducing air pollution.
- It is especially useful in coal-burning power plants and in industrial operations that generate large quantities of smoke.
- Electrostatic precipitator consists of a wire maintained at negative potential running down the center of a duct and the outer wall kept grounded.
- A high voltage (typically 40Kv to 100Kv) is maintained between a wire running down the center of a duct and the outer wall, which is grounded.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like:
    - Can you recall and explain the fundamental principles behind the operation of an electrostatic precipitator?
    - What role do static electric fields play in the operation of electrostatic precipitator?
    - Identify and discuss the key components of an electrostatic precipitator.
    - How does the electrostatic precipitator contribute to environmental conservation, and what specific pollutants does it target?
    - What were the key takeaways for you from today's discussion on electrostatic precipitator?
    - Can you recall specific applications where electrostatic precipitator had a positive impact on air quality?
    - Discuss any challenges or limitations associated with electrostatic precipitators.

Assignment and closure

(5 min)

- Explain in detail the principles and mechanism behind the operation of an electrostatic precipitator.
- Identify and describe the key components of an electrostatic precipitator.
- Explore strategies for raising awareness and educating communities about the benefits of electrostatic precipitators in air pollution control.
- Investigate and provide examples of applications where electrostatic precipitators are commonly used.

Episode – Twenty

Topics: Direct Current Circuit

Sub topics: Basic concepts

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 619-621.
- Principles of Physics by Koirala R. et al. (2016)– page no. 218 - 233.

Learning Outcome:

By the end of this class, students should be able to:

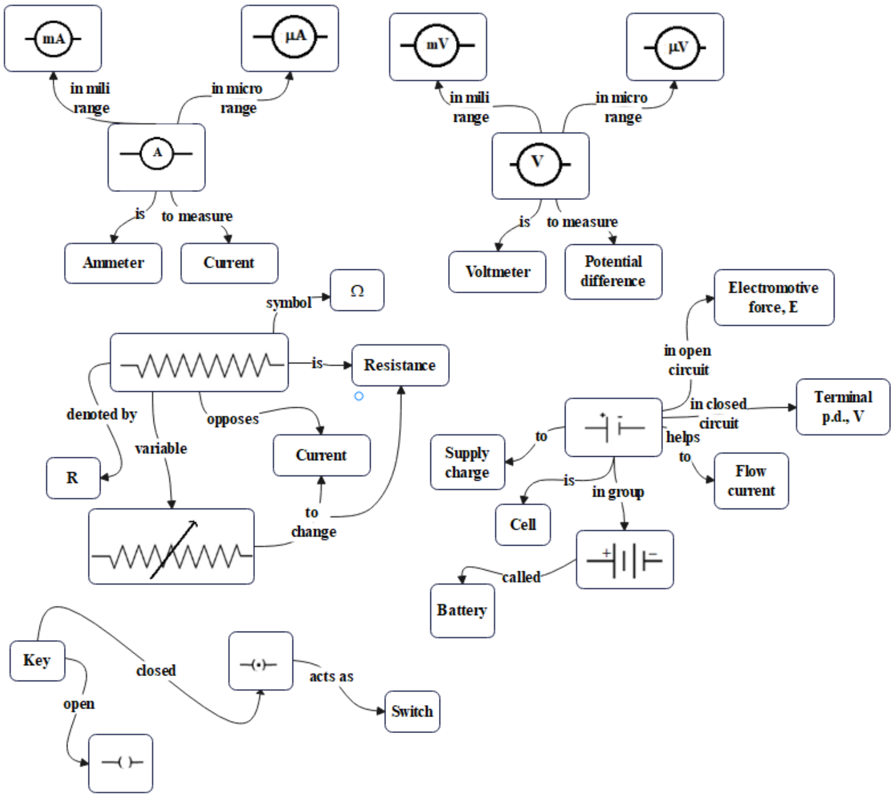
- Know the meanings of terms Resistance, Resistivity, Conductance, and Conductivity.
- Understand the units and dimensions of related terms.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- Warm up the students about the previous class by showing the concept map and asking few questions related to
  - Symbols like ammeter, voltmeter, resistance, cell, key and their function in electric circuit.
  - Charge on electron
  - Charge on proton
  - Flow of charge



Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

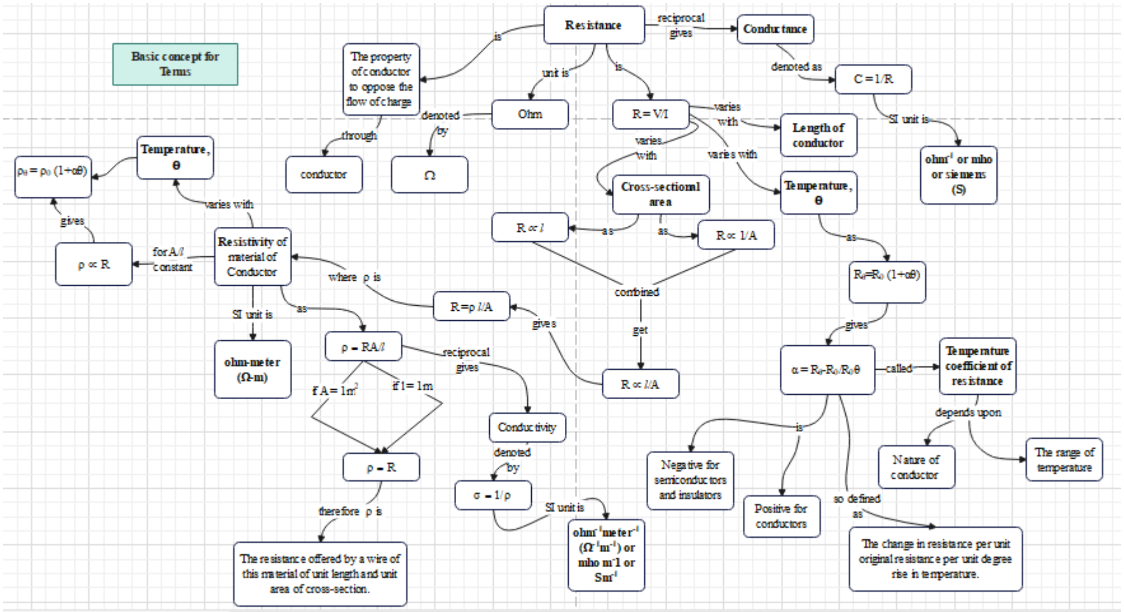
(5 min)

- Present the term Resistance, Resistivity, Conductance, and Conductivity as an advance organizer.
- Give a brief overview of terms related to Resistance, Resistivity, Conductance, and Conductivity.

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe Resistance, Resistivity, Conductance, and Conductivity by presenting concept map as follows:



- Define the terms resistance and resistivity by drawing concept maps on board and elaborate each term by differentiating the main concepts into sub - concepts in hierarchically order.
- Explained the students about all sub concepts related with resistance and resistivity with illustrations by showing into same concept map.

(5min)

- Furthermore, defined all the remaining terms related with conductance by presenting a

  same concept map.
- In addition, gave an expression, formula and units for each term and explained them.

(5 min)

- Moreover, gave an expression, formula and units for each term related to conductivity and explained them.
- Finally, concluded the basic concepts of Resistance, Resistivity, Conductance, and Conductivity by showing in same concept map.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the basic information of Resistance, Resistivity, Conductance, and Conductivity by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with Resistance, Resistivity, Conductance, and Conductivity by showing same concept map providing with illustrations to get final propositions as:
  - The resistance of a conductor is defined as the property by virtue of which the conductor opposes the flow of current through it.

- The resistance of a conductor is expressed by $\mathrm{R} = \frac{\mathrm{V}}{\mathrm{I}}$.
- The S.I. unit of resistance is **ohm** (Ω). It is also the practical unit of resistance.
- The resistance of conductor is a scalar quantity.
- The resistivity of a conductor is defined as the ratio of the Electric field applied to the Current density. It can be denoted by ρ.
- The resistance and resistivity can be related as $\mathrm{R} = \frac{\rho \mathrm{l}}{\mathrm{A}}$.
- The resistivity is a constant quantity for a particular material of conductor.
- The S.I. and practical unit of resistivity is **ohm-meter** (Ω-m).
- The conductance of a conductor is the ease with which electric charges flow through it. It is equal to the reciprocal of its resistance and is denoted by C.
- The relation of conductance with resistance of a conductor can be expressed as $C = \frac{1}{R}$.
- The SI unit of conductance is **ohm^{-1}** or **mho** or **siemens (S)**.
- The reciprocal of the resistivity of a material is called its conductivity and is denoted by σ.
- The relation of conductivity and resistivity can be expressed as $\sigma = \frac{1}{\rho}$.

- The SI unit of conductivity is **ohm^{-1}m^{-1}** or **mho m^{-1}** or **Sm^{-1}**.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - What is resistance?
    - Explain relation of resistance with length of a conductor and its cross-sectional area.
    - What is the relationship between resistance and conductance, resistance and resistivity, resistivity and conductivity?

Assignment and closure

(5 min)

- Derive the relation $R = \frac{\rho l}{A}$, where symbols have their usual meanings.
- Make a concept map by own showing the relationship between R, ρ, C and σ with their units.

Episode – Twenty-One

Topics: Mechanism of conduction

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 619-621.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 3-4.

Learning Outcome:

By the end of this class, students should be able to:

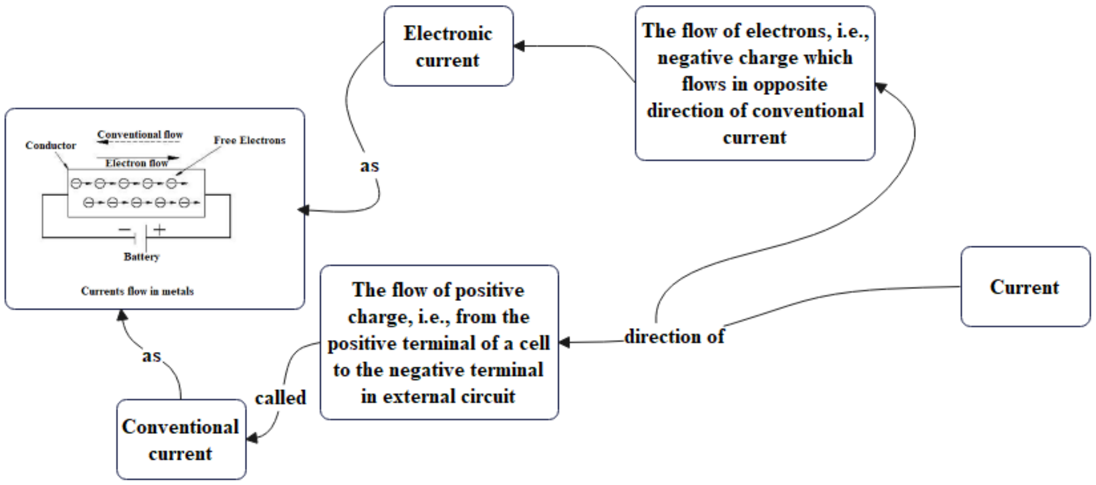
- know the meanings of terms Drift velocity.
- derive the relationship between electric current and drift velocity.
- understand the mechanism of conduction of electrons in a conductor.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- Warm up the students about the previous class by asking few questions related to
  - Charge on electron
  - Charge on proton
  - Flow of charge
  - Direction of current
- Draw a concept map showing the direction of current as follows:



Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

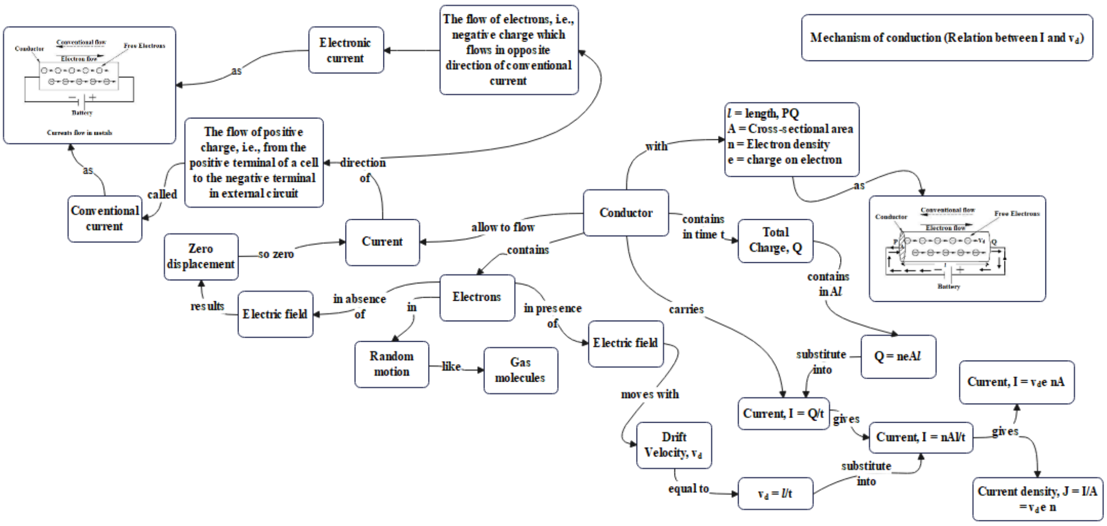
(5 min)

- Present the term conductor, current, drift velocity, and mechanism of conduction as an advance organizer.
- Give a brief overview of terms related to conductor, current, drift velocity, and mechanism of conduction

Phase – II: Presentation of learning Task or Material

(5 min)

- Describe conductor, current, drift velocity, and mechanism of conduction by presenting concept map as follows:



- Discuss the terms related to mechanism of conduction like conductor, current and drift velocity by drawing concept maps on board and elaborate each term by differentiating the main concepts into sub -concepts in hierarchically order.
- Elaborated the mechanism of conduction mechanism by taking the use of same concept map.
- Described the movement of electrons in absence and presence of electric field.
- Explained the concept of zero current in absence of electric field even though there are large number of electrons in a conductor.

(5 min)

- Explained the students about all sub concepts related with mechanism of conduction like conductor, current and drift velocity with illustrations by showing into same concept map.
- Furthermore, defined all the remaining terms related with mechanism of conduction by presenting a

  same concept map.

(5 min)

- Moreover, calculated an expression $I = v_d enA$, and $J = v_d en$, formula and units for each term related to mechanism of conduction.
- Explain each term involved by using same concept map.
- Finally, concluded the basic concepts of mechanism of conduction like conductor, current and drift velocity by showing in same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the basic information of mechanism of conduction like conductor, current and drift velocity by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with mechanism of conduction like conductor, current and drift velocity by showing same concept map providing with illustrations to get final propositions as:
    - A metal has number of free electrons moving randomly.
    - Under the application of electric field electron moves from one end to another end.
    - During motion electrons collide with lattice i.e., positive charge and they lose some of their energy but due to the applied electric field they will accelerate and again gain energy. By this process electron moves with average velocity in presence of electric field called drift velocity and can be denoted by V_d.
- The relation of electric current and drift velocity as $I = \frac{q}{t} = \frac{nAv_d te}{t} = nAv_d e.$
- Using $J = \frac{I}{A}$ this equation can be written as, $\frac{I}{A} = nv_d e \Rightarrow J = nv_d e \Rightarrow v_d = \frac{J}{ne}.$

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - ➢ Define drift velocity?
    - ➢ Why there is zero current in absence of electric field even though there are large number of free electrons moving randomly in a conductor?
    - ➢ What is current density?

Assignment and closure

(5 min)

- Derive the relation of electric current with drift velocity as $I = v_d enA$, where symbols have their usual meanings.
- Make a chart of circuit showing the direction of conventional current and electronic current.

Episode – Twenty-Two

Topics: Ohm's law and verification

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 633-635.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 6-7.

Learning Outcome:

By the end of this class, students should be able to:

- understand statement of the Ohm's law.
- verify the Ohm's law by using ammeter and voltmeter.
- define ohmic and non-ohmic conductors.
- know the expression of variation of resistance of conductor with variation of temperature.
- understand the term temperature coefficient of resistance and resistivity.

In class activity (45 min)

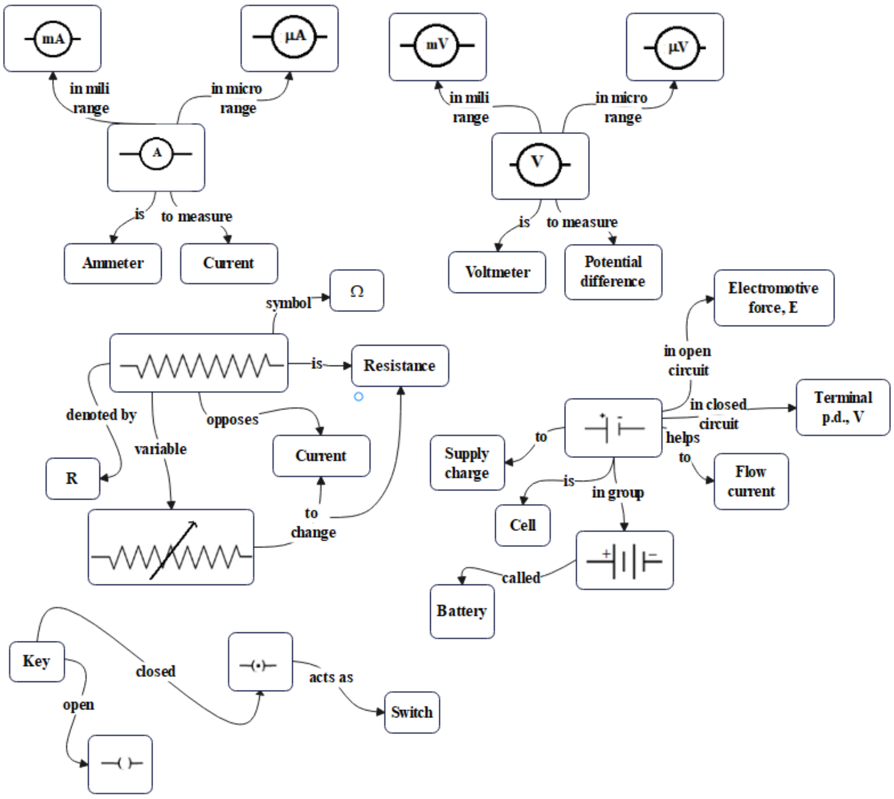
Introducing (10*min*)

Start the class by asking the students about:

- Warm up the students about the previous class by asking few questions related to
    - ➢ Potential difference
    - ➢ Electric current
    - ➢ Resistance

- ➢ Ammeter and voltmeter

- Draw a concept map showing the all the terms mentioned above.



Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

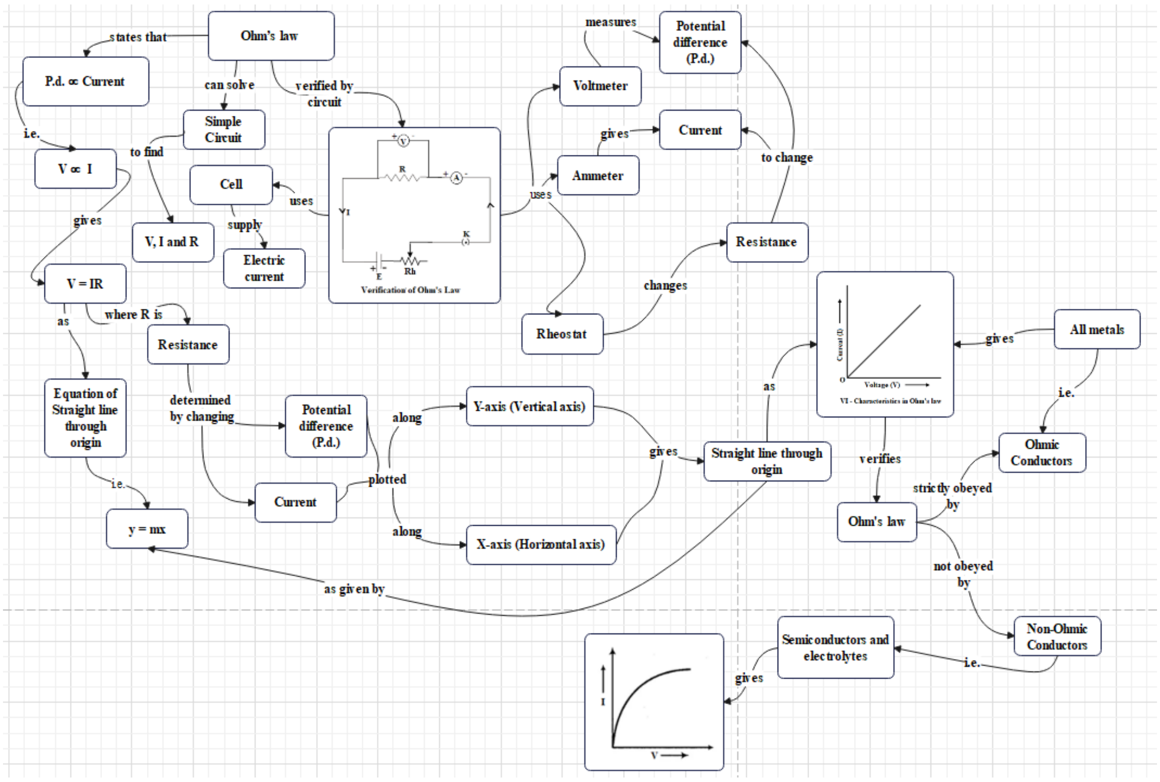
(5 min)

- Present the term Ohm’s law in advance as an advance organizer.
- Give a brief overview of terms related to Ohm’s law.

Phase – II: Presentation of learning Task or Material

(5 min)

- State the Ohm’s law and discuss the relation of potential difference with current by drawing a concept map on a board as follows:



- Described the terms related to ohm's law by showing into same concept map and elaborated each term by differentiating the main concepts into sub - concepts in hierarchically order.
- Explained the circuit diagram containing ammeter, voltmeter and rheostat in same concept map.
- Described the process of variation of current with variation of voltmeter due to the adjustment of rheostat by differentiating the main concepts into sub - concepts in hierarchically order in same concept map.

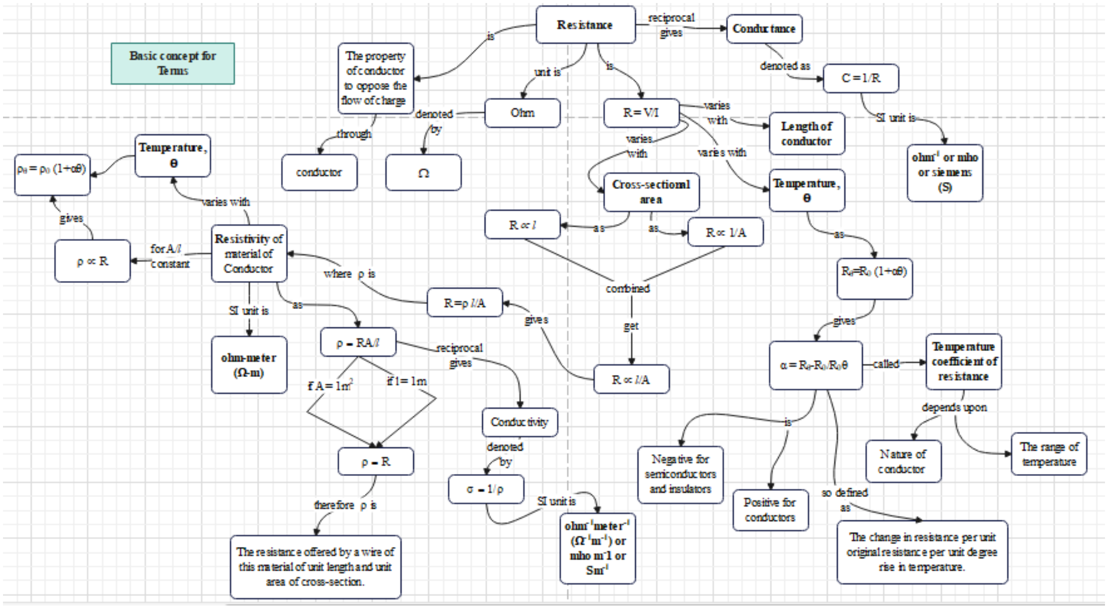
(5 min)

- Explained the students about all sub concepts by giving illustration in same concept map.
- Explained the process of verification of Ohm's law by observing the current with corresponding value of potential difference in ammeter and voltmeter respectively.

- Discussed the plotting of V-I characteristic to verify Ohm’s law by showing linear relationship between V and I i.e., $V \propto I$.
- Gave an illustration of conductor which obey the ohm’s law and do not obey this law.
- Pointed out some examples of ohmic and non-ohmic conductors.
- Explain each term involved by using same concept map.

(5 min)

- Moreover, described the relation of variation of resistance with variation of temperature as $R_\theta = R_0(1 + \alpha\theta)$ in a conductor by giving second concept map as follows:



- Defined the term temperature coefficient of resistance and pointed out its unit in same concept map.
- Discussed the temperature coefficient of resistance of a conductor, insulators and semiconductors.
- Described briefly how the resistivity vary with temperature by drawing a concept map as $\rho_\theta = \rho_0(1 + \alpha\theta)$.

- Finally, concluded the basic concepts of ohm's law and temperature dependence of resistance by showing in above two concept maps.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the basic information of ohm's law and temperature dependence of resistance by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with ohm's law and temperature dependence of resistance by showing same concept map providing with illustrations to get final propositions as:
  - At constant temperature, the current (I) flowing through a conductor is directly proportional to the potential difference (V) across its ends. That is $I \propto V$

$$\therefore V = RI$$

- The conductors which obey the ohm's law strictly are called ohmic conductors and the resistance of those conductors are called ohmic resistance. Example: All metals are ohmic resistance.
- The conductors which do not flow ohm's law are called non-ohmic conductors. For example: The electrolytes ($AgNo_3$, $CuSo_4$ etc.), the semiconductors, the super conductors, vacuum tubes etc. are non-ohmic.
- The general expression for a resistance of pure metal at temperature θ^0C is

$$R_\theta = R_0(1 + \alpha\theta)$$

  - Temperature coefficient of resistance denoted by α is defined as the change in resistance per unit original resistance per unit degree rise in temperature.

i.e. $\alpha = \frac{R_\theta - R_0}{R_0\theta}$

- As R α ρ, the resistivity at θ^0C becomes $\rho_\theta = \rho_0(1 + \alpha\theta)$, Where α is the temperature coefficient of resistivity.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
  - State Ohm's law.
  - How potential difference developed across a conductor vary with electric current flowing through it?
  - What is ohmic and non-ohmic conductors?
  - Give examples of ohmic and non-ohmic conductors.
  - Define temperature coefficient of resistance.
  - Why semiconductors have negative temperature coefficient of resistance?

Assignment and closure

(5 min)

- State Ohm's law and explain the process of verification of it by using an ammeter and a voltmeter.
- Make a chart of well labelled circuit showing the verification of Ohm's law.
- What is temperature coefficient of resistance? Write down its unit.
- Define ohmic and non- ohmic conductors. Draw a I-V characteristic for each of them.

Episode – Twenty- Three

Topics: Combination of resistors

Sub topics: Parallel combination

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 633-635.
- A textbook of Physics (II) by Satish K. Gupta & J.M. Pradhan (September 1987) – page no. 11-12.

Learning Outcome:

By the end of this class, students should be able to:

- understand the parallel combination of resistance.
- calculate an equivalent resistance in parallel combination.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- Warm up the students about the previous class by asking few questions related to
    - Potential difference
    - Electric current
    - Resistance
    - Ammeter and voltmeter
- their any personal experiences or observations in daily life related to resistances and their combination.

- their perceptions or misconceptions about resistance.
- real-world applications of resistance.
- targeted questions to prompt students' recall and engagement.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

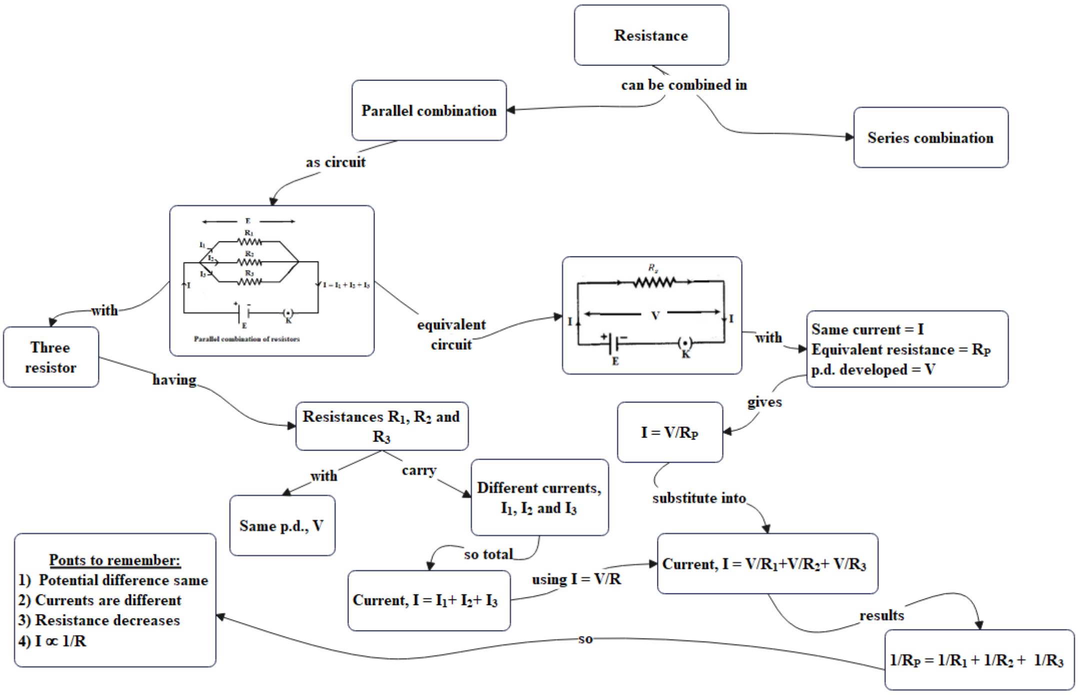
(5 min)

- Present the term parallel combination of resistance as an advance organizer.
- Give a brief overview of terms related to resistance.

Phase – II: Presentation of learning Task or Material

(5 min)

- Described parallel combination of resistance by presenting concept map as follows:



- Described the parallel combination of resistance by taking a circuit diagram containing three resistors in the parallel combination on the same concept map.

- Explain the students about all sub concepts related to parallel combination of resistance by showing the same concept map.
- Described the process of variation of potential difference through the resistors in the combination and restate the parallel combination in terms of potential difference through parallel combination. by differentiating the main concepts into sub -concepts in hierarchically order in same concept map.

(5 min)

- Furthermore, explained the process of calculating an equivalent resistance of parallel combination containing three resistors by using Ohm's law relation V = IR.
- Described how resistance decreases in parallel combination.
- Explain each term involved by using same concept map.

(5 min)

- Moreover, described the process of variation of electric current through the resistors in the combination in same concept map.
- Explained the algebraic sum of electric current due to a scalar quantity as total electric current, $I = I_1 + I_2 + \cdots I_n$.
- In addition, described the relation between current and resistance in the circuit for the given combination as $I \propto \frac{1}{R}$.
- Elaborated the concept of equivalent circuit for combination and relation obtained from it.
- Finally, concluded the parallel combination of resistance and its usefulness by showing in same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of parallel combination of resistance by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with parallel combination of resistance by showing same concept map providing with illustrations to get final propositions as:

- Two or more resistances are said to be connected in series, if potential difference across each of them is equal to the applied potential difference.
- In series resistance circuit, Voltage across each resistor is same and is equal to the applied voltage.
- In series combination of resistance, the reciprocal of total resistance in the circuit is the sum of the reciprocal of individual resistances including that of the cell.
- Total current = sum of the currents through the individual resistances.
- In parallel combination, currents through various resistance are inversely proportional to the individual resistances.
- In series combination of resistance, equivalent resistance is less than the smallest individual resistance.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - ➢ What is parallel combination of resistance?

  - How electric current through a resistor vary with resistance connected in combination?
  - What is an equation of equivalent resistance in parallel combination?

Assignment and closure

(5 min)

- Discuss the parallel combination of resistors and derive an equivalent resistance of n resistor each of resistance R in the combination.
- Make a chart of well labelled circuit showing the calculation of equivalent resistance in parallel combination containing four resistors.

Episode – Twenty - Four

Topics: Galvanometer

Sub topics: Shunt and conversion of galvanometer into ammeter

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 633-635.
- Principles of Physics by Koirala R. et al. (2016)– page no. 243 - 245.

Learning Outcome:

By the end of this class, students should be able to:

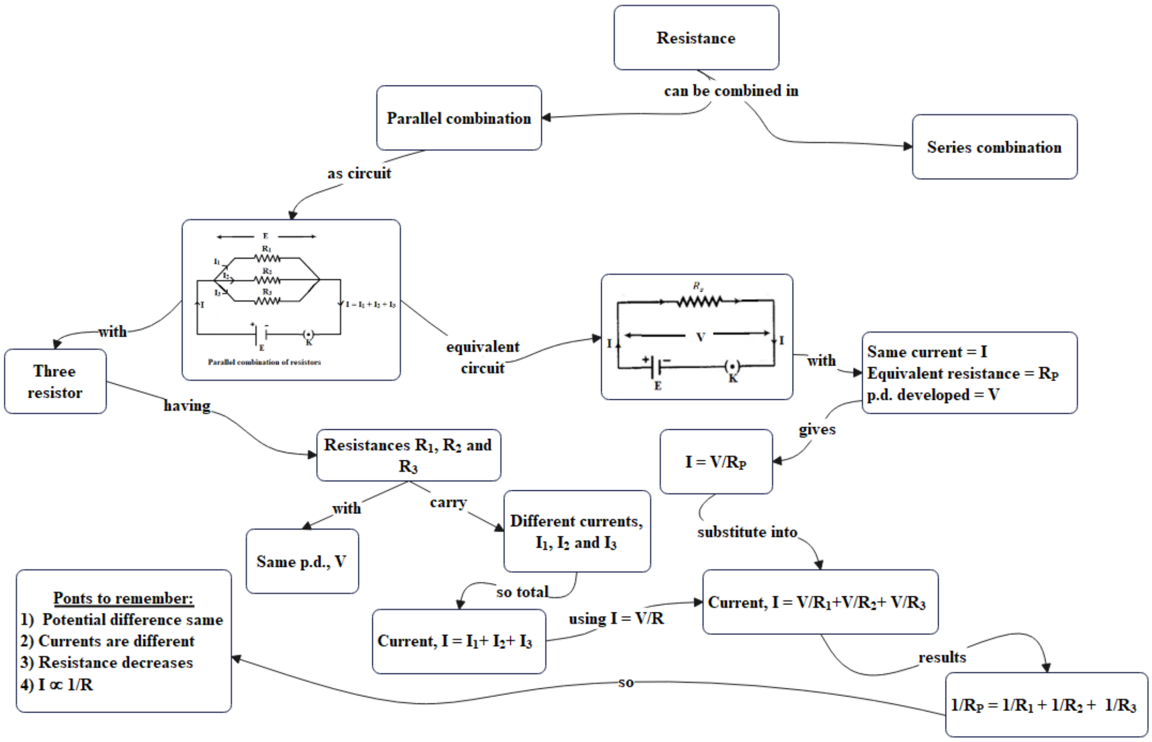
- understand an instrument galvanometer and its function.
- define the meaning of shunt.
- convert the galvanometer into ammeter.

In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- Warm up the students about the previous class by asking few questions related to
    - Potential difference
    - Parallel combination of resistors
    - Ammeter
- A concept map for recalling parallel combination of resistance is drawn as shown below:



- their any personal experiences or observations in daily life related to galvanometer and its use.
- their perceptions or misconceptions about shunt and galvanometer.
- real-world applications of galvanometer.
- targeted questions to prompt students' recall and engagement.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

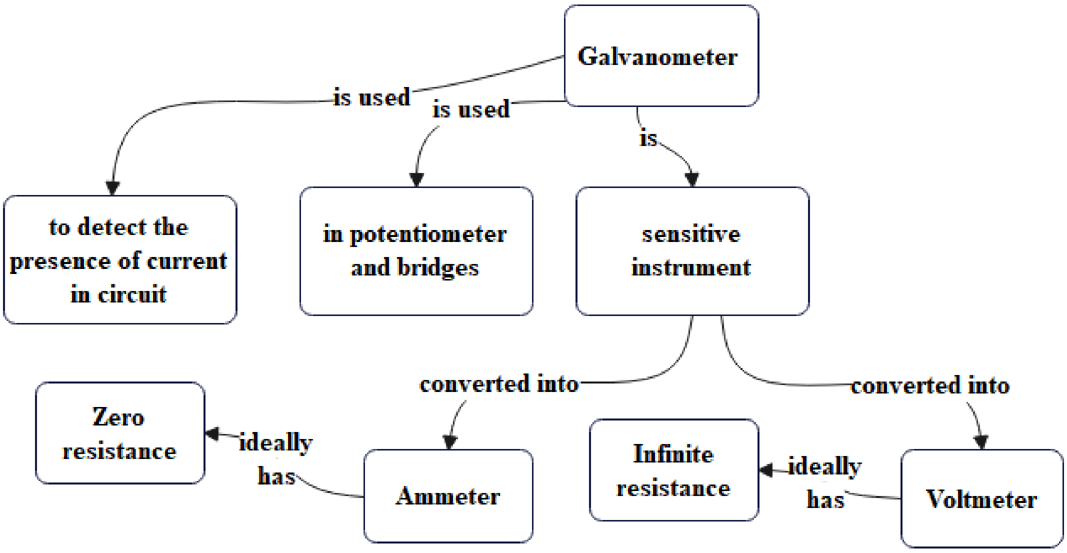
(5 min)

- Present the term shunt and conversion of galvanometer into ammeter as an advance organizer.
- Give a brief overview of terms related to galvanometer.

Phase – II: Presentation of learning Task or Material

(5 min)

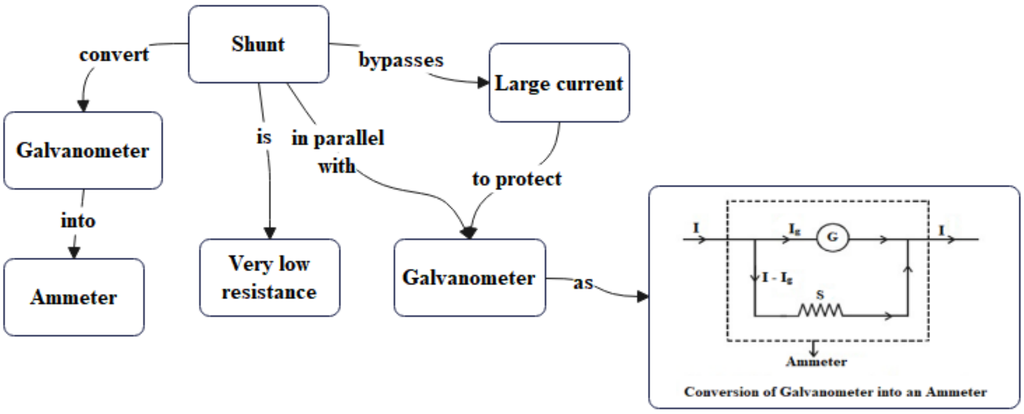
- A concept map of galvanometer along its function is drawn as shown below:



- Described the galvanometer as a sensitive instrument.
- Elaborated the use of galvanometer to give null deflection in potentiometer and
- Present the term galvanometer in advance as advance organizer.
- Describe the galvanometer as a sensitive instrument.
- Discuss the use of galvanometer to give null deflection in potentiometer and bridges.
- Explain the students about all sub concepts related to parallel combination of resistance by showing the same concept map.
- Described the process of variation of potential difference through the resistors in the combination by differentiating the main concepts into sub -concepts in hierarchically order in same concept map.

(5 min)

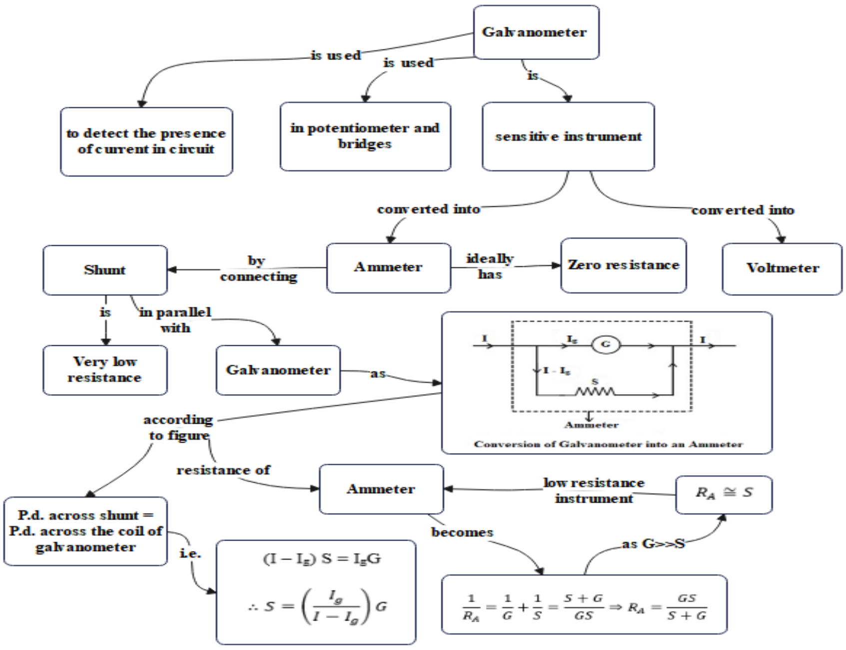
- Furthermore, described the meaning of shunt and its function by showing in another concept map as:



- Explained shunt by differentiating the main concepts into sub -concepts in hierarchically order in same concept map.
- Explain each term involved by using same concept map.

(5 min)

- Moreover, described the process of conversion of galvanometer into an ammeter of range (0 – I) by presenting a new concept map as follows:



- Described the calculation of shunt as

$$S = \left(\frac{I_g}{I - I_g}\right) G$$

- In addition, explained the all terms used in above equation.
- Calculated the value of resistance of newly generated ammeter as

$$\frac{1}{R_A} = \frac{1}{G} + \frac{1}{S} = \frac{S+G}{GS} \Rightarrow R_A = \frac{GS}{S+G}$$

$$\therefore R_A \cong S$$

- Explained why ammeter is always connected in series with circuit components by showing the same concept map.
- Finally, concluded the parallel combination of resistance and its usefulness in conversion of galvanometer into an ammeter by showing in same concept map.

(5min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of shunt and conversion of galvanometer into ammeter by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with shunt and conversion of galvanometer into ammeter by showing same concept map providing with illustrations to get final propositions as:

- The galvanometer is the device used for detecting the presence of small current and voltage or for measuring their magnitude.
- The galvanometer is mainly used in the bridges and potentiometer where they indicate the null deflection or zero current.
- Shunt is a low resistance connected always in parallel to the galvanometer.

- Being a low resistance very large amount of current is passed through it and only remaining lower amount of current is flow through the Galvanometer.
- Shunt can be used to convert galvanometer to an ammeter.
- The current can be increased through a circuit containing galvanometer by connecting the shunt across it which decreases the resistance in circuit.
- The resistance of an ideal ammeter is zero. So, as ammeter is an instrument of low resistance, it is always connected in series with the circuit.
- Because of the low resistance, the resistance of the circuit does not increase due to its introduction and hence the current in the circuit is not affected.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like
    - ➢ What is shunt?
    - ➢ How galvanometer can be changed into an ammeter.

Assignment and closure

(5 min)

- Discuss the shunt and its function. Explain how the shunt is used to convert a given galvanometer into an ammeter.
- Make a chart of well labelled circuit showing the conversion of galvanometer into an ammeter.

Episode – Twenty-Five

Topics: Galvanometer

Sub topics: Conversion of galvanometer into Voltmeter

Time: 45 minutes

Pre-class:

Reading books:

- Advanced Level Physics (Fifth edition) by Nelkon & Parker Arnold (New Edition 2004) – page no. 633-635.
- Principles of Physics by Koirala R. et al. (2016)– page no. 243 - 247.

Learning Outcome:

By the end of this class, students should be able to:

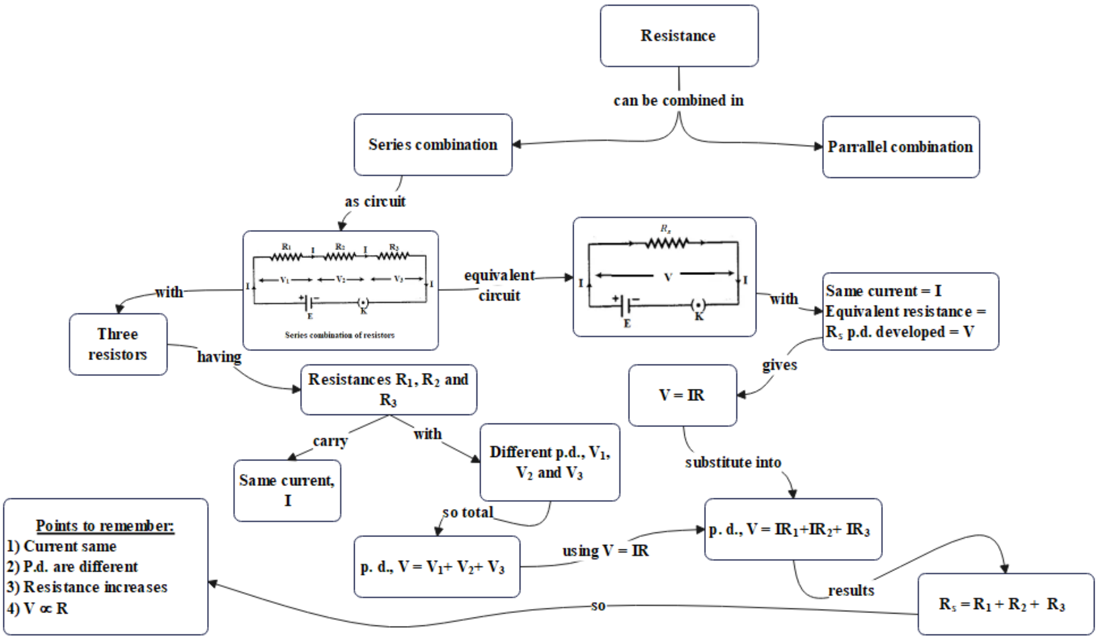
- understand an instrument galvanometer and its function.
- define the meaning of Multiplier.
- convert the galvanometer into Voltmeter.

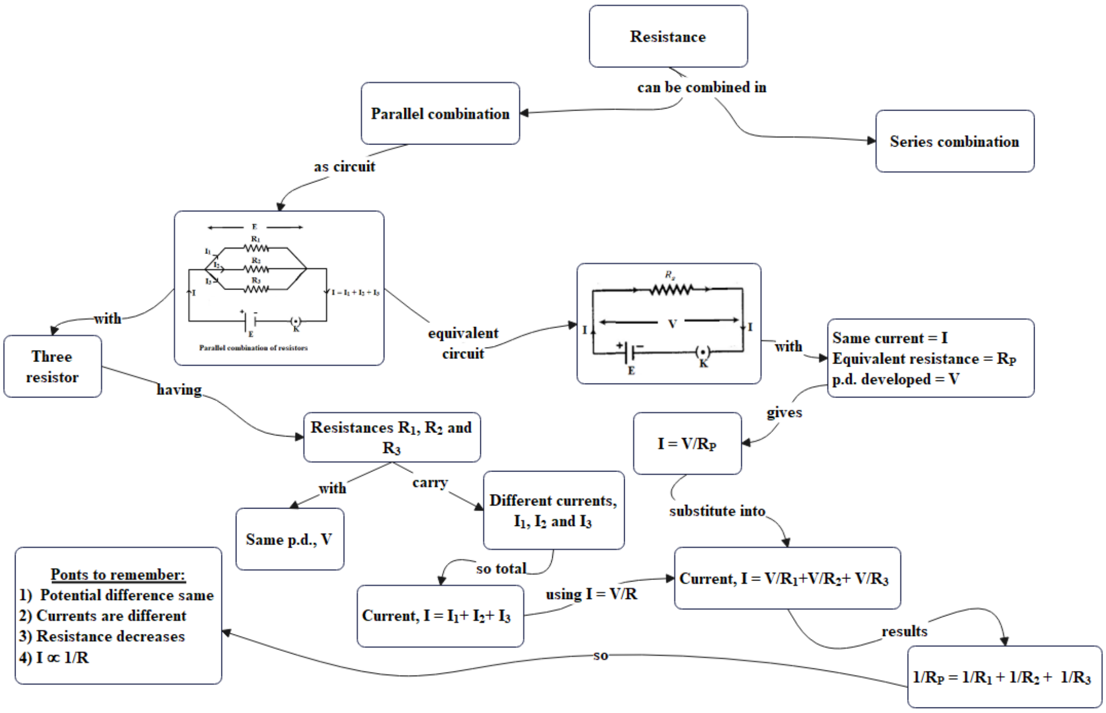
In class activity (45 min)

Introducing (10*min*)

Start the class by asking the students about:

- Warm up the students about the previous class by asking few questions related to
    - Potential difference
    - Series combination
    - Parallel combination of resistors
    - Voltmeter
- A concept map for recalling series and parallel combination of resistance is drawn as shown below:





- their any personal experiences or observations in daily life related to galvanometer and its use.
- their perceptions or misconceptions about multiplier i.e. high resistance and galvanometer.

- real-world applications of galvanometer.
- targeted questions to prompt students' recall and engagement.
- to share their insights and questions related to the upcoming topic.

Teaching (25*min*)

Phase – I: Presentation of Advance Organizer

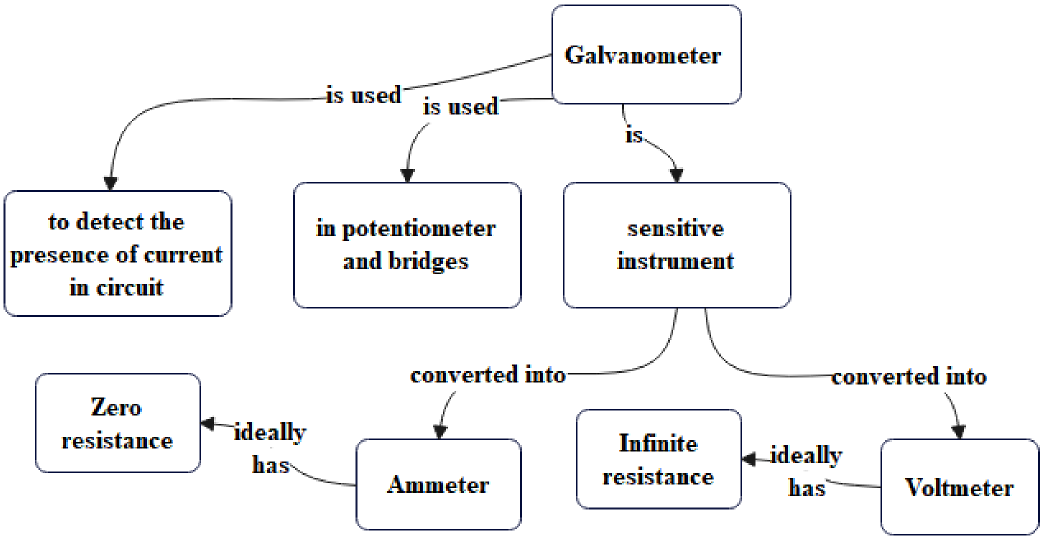
(5 min)

- Present the term multiplier and conversion of galvanometer into voltmeter as an advance organizer.
- Give a brief overview of terms related to galvanometer.

Phase – II: Presentation of learning Task or Material

(5 min)

- A concept map of galvanometer along its function is drawn as shown below:

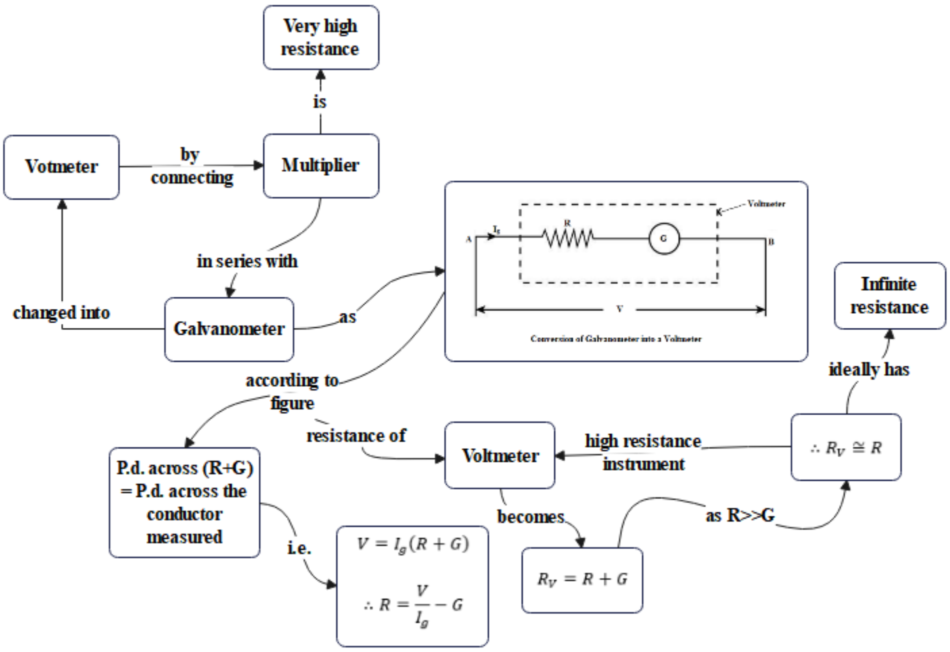


- Present the term galvanometer in advance as advance organizer.
- Described the galvanometer as a sensitive instrument.
- Elaborated the use of galvanometer to give null deflection in potentiometer and
- Describe the galvanometer as a sensitive instrument.

- Discuss the use of galvanometer to give null deflection in potentiometer and bridges.
- Explain the students about all sub concepts related to series and parallel combination of resistance by showing the same concept map.
- Described the process of variation of potential difference through the resistors in the combination by differentiating the main concepts into sub -concepts in hierarchically order in same concept map.

(5 min)

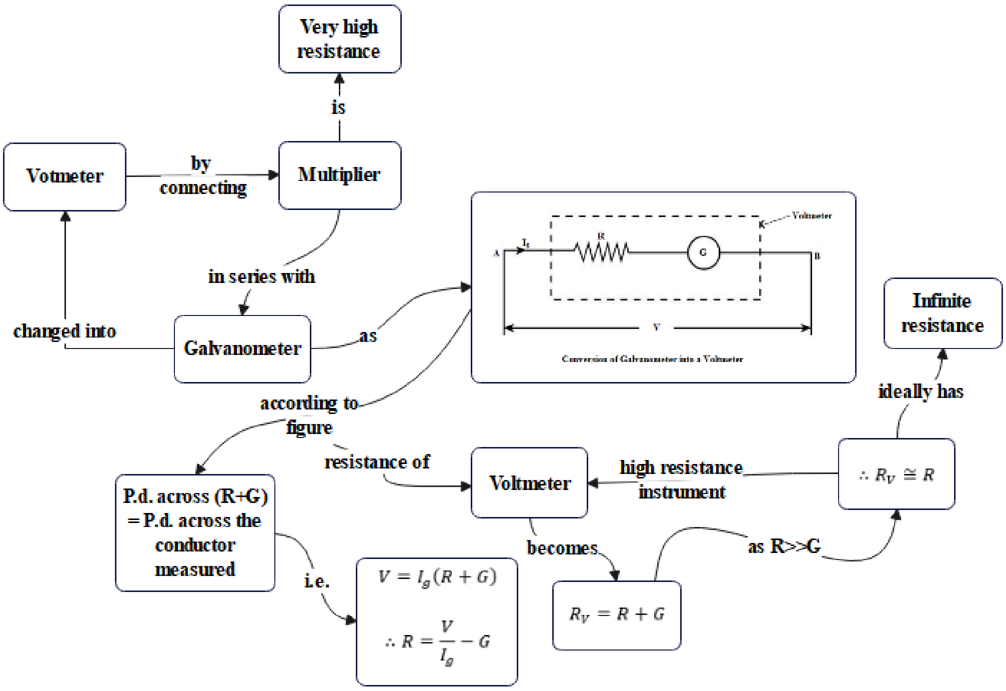
- Furthermore, described the meaning of multiplier and its function by differentiating the main concepts into sub -concepts in hierarchically order in concept map as follows:



- Explain each term involved by using same concept map.

(5 min)

- Moreover, described the process of conversion of galvanometer into a voltmeter of range (0 – V) by presenting a new concept map as follows:



- Described the calculation of multiplier as

$$V = I_g(R + G)$$

$$\therefore R = \frac{V}{I_g} - G$$

- In addition, elaborated the all terms used in above equation.
- Calculated the value of resistance of newly generated ammeter as

$$R_V = R + G$$

$$\therefore R_V \cong R$$

- Explained why a voltmeter is always connected in parallel with circuit components by showing the same concept map.
- Finally, concluded the series and parallel combination of resistance and its usefulness in conversion of galvanometer into a voltmeter by showing in same concept map.

(5 min)

- Differentiate all the concepts into sub-concepts in the concept map that give the information of multiplier and conversion of galvanometer into voltmeter by linking with appropriate verbs.
- Also, reconcile integration of all sub concepts related with multiplier and conversion of galvanometer into voltmeter by showing same concept map providing with illustrations to get final propositions as:

- The galvanometer is the device used for detecting the presence of small current and voltage or for measuring their magnitude.
- The galvanometer is mainly used in the bridges and potentiometer where they indicate the null deflection or zero current.
- Multiplier is a high resistance connected always in series with the galvanometer.
- Being a high resistance very small amount of current is passed through galvanometer and all required amount of current is flow through the circuit component.
- Shunt can be used to convert galvanometer to an ammeter.
- The resistance of an ideal voltmeter is infinite. So, as voltmeter is an instrument of high resistance, it is always connected in parallel with the circuit element across which potential difference has to be measured.
- Because of the high resistance, the resistance of the circuit increases due to its introduction and hence the less current is drawn without any effect.

Post-class

Phase – III: Recapitulation

(5 min)

- Ask the questions and give feedback (If necessary) like

- What is multiplier?
- How galvanometer can be changed into a voltmeter.

Assignment and closure

(5 min)

- Explain how the multiplier is used to convert a given galvanometer into a voltmeter of range (0-V).
- Make a chart of well labelled circuit showing the conversion of galvanometer into a voltmeter.

Appendix XV: Interview Guideline for Students and Teachers

a) Interview Guideline for Students (Experimental Group)

In the semi-structured interviews, students were asked about their perceptions of concept mapping, its benefits, and moments of elation and motivation it provided. They discussed how concept mapping created opportunities for deeper understanding and engagement in Physics, as well as the challenges they encountered with this method.

Perceptions of Concept Mapping

1. What is the nature and essence of the physics subject?
2. Do you know about the concept mapping strategy of teaching?
3. How comfortable do you feel using the concept mapping method of teaching in the topic electrostatics and electricity?

Benefits of Concept Mapping

4. What do you see as the benefits of concept mapping in learning science?
5. In your opinion, what are the benefits or advantages of using concept mapping as a learning tool in Physics education? How does it enhance your understanding and engagement with the subject?

Elation by Concept Mapping

6. Can you share a specific instance where you felt happy, joyful, or elated while using concept mapping to learn Physics? What aspects of the method contributed to these positive emotions?
7. How do you feel when you successfully create a concept map for a Physics topic? Does it provide you with a sense of accomplishment or confidence in your knowledge?

Motivation by Concept Mapping

8. Have you noticed any changes in your attitudes or motivation towards learning Physics since you started using the concept mapping method? If yes, please elaborate on those changes and how they have influenced your learning experience.
9. Have you ever used concept mapping to explain a Physics concept to your peers or classmates? How did it feel to be in the role of a teacher, and what impact did it have on your own understanding of the topic?

Opportunities by Concept Mapping

10. Overall, how do you believe the concept mapping method has influenced your learning experience in Physics? Do you feel it has made the subject more enjoyable, accessible, or memorable? Please explain.
11. In your opinion, how does the concept mapping method contribute to creating a positive and engaging classroom environment? Does it encourage collaboration, communication, or critical thinking among students? Please share any relevant experiences.

Challenges Faced in Concept Mapping

12. What type of challenges did you face in learning science while being taught through the concept mapping strategy?
13. Have you encountered any challenges or obstacles while using the concept mapping method in your Physics learning? If so, could you describe one such challenge and how you overcame it?

b) Interview Guideline for Teachers (Experimental Group)

In the semi-structured interviews, teachers were asked about their experiences and perceptions related to the concept mapping method in teaching Physics. The questions explored various themes:

Perceptions of Concept Mapping

1. How many students are in the bachelor-level science education class?
2. Please tell me a little bit about your experience in teaching Physics.
3. Which teaching methods do you like the most in Physics?
4. Do you know about the concept mapping strategy of teaching? Could you explain what it entails and how it can be used in the context of Physics education?

Benefits of Concept Mapping

5. Are the students learning and understanding more from the concept mapping teaching strategy?
6. Did the concept mapping method make it easier to memorize physical phenomena and derive relations?
7. Reflecting on your experiences, what are some of the benefits or advantages of using the concept mapping method specifically for teaching Physics? How does it enhance the learning experience for your students?

Elation by Concept Mapping

8. Can you share a specific instance when you observed your students experiencing joy or elation while learning Physics through concept mapping? What factors do you think contributed to their positive emotional response?

9. What are the key non-cognitive factors that contribute to creating a happy and joyful learning environment in the context of Physics education? How do you prioritize and address these factors in your teaching practice?

Motivation by Concept Mapping

10. What motivated you to use the concept mapping method in your Physics teaching?
11. Have you noticed any changes in your students' attitudes or motivation towards Physics since you started using the concept mapping method? If so, how would you describe these changes, and what role do you think the method played in influencing them?

Opportunities by Concept Mapping

12. Does concept mapping method make physics interesting?
13. Do you think you will use concept mapping in other courses or endeavors? Please explain.
14. Can you share a memorable teaching and learning moment where you witnessed a significant breakthrough or improvement in your students' understanding of a Physics concept through the concept mapping method? How did that impact your teaching approach?

Challenges Faced in Concept Mapping

15. How comfortable do you feel using the concept mapping method of teaching in this topic?
16. Do you have any concerns or complaints about using concept mapping in this course? Please explain.

17. Can you describe a problem or obstacle you faced while implementing the concept mapping method in your Physics classroom? How did you address it, and what did you learn from that experience?
18. What did you like/dislike about using concept maps?
19. What strategies do you employ to maintain a positive and engaging classroom atmosphere while using the concept mapping method? How do you ensure that all students feel included, motivated, and supported in their learning journey?

c) Interview Guideline for Students (Control Group)

In the semi-structured interviews, students were asked about their perceptions of conventional method of teaching, its benefits, and moments of elation and motivation it provided. They discussed how this teaching method created opportunities for deeper understanding and engagement in Physics, as well as the challenges they encountered with this.

Perceptions of Physics Teaching by Current Teaching Method

1. What is your overall perception of the physics subject?
2. How do you feel about the teaching method used in your physics classes?
3. How comfortable are you with the teaching methods used for topics like electrostatics and electricity?

Benefits of Current Teaching Method

4. What do you think are the strengths of the teaching method used in your physics class?
5. How does this method help you understand and engage with physics concepts?

Elation by Current Teaching Method

6. Can you recall a specific moment when you felt proud or satisfied while learning physics? What led to these feelings?
7. How do you feel when you successfully solve a physics problem or grasp a concept during lessons? Does it give you a sense of accomplishment?

Motivation by Current Teaching Method

8. Have you noticed any changes in your motivation to learn physics over time? If yes, can you describe these changes and how they have affected your learning experience?
9. Have you ever explained a physics concept to your peers? How did it feel, and did it improve your own understanding?

Opportunities by Current Teaching Method

10. How do you feel this teaching method has influenced your learning experience in physics? Do you find the subject more accessible or enjoyable? Please explain.
11. Do you think the current teaching method encourages collaboration, communication, or critical thinking among students? Can you share an example?

Challenges Faced in Current Teaching Method

12. What challenges have you faced while learning physics with the current teaching method?
13. Have you encountered any difficulties in understanding or retaining concepts? If so, how have you tried to overcome them?

d) Interview Guidelines for Teachers (Control Group)

During the semi-structured interviews, teachers were formally and informally questioned about their views on teaching physics using the conventional method, along with their experiences, and instances of excitement and motivation it generated. They shared how the conventional teaching method offered opportunities for deeper teaching insights and engagement in physics while also addressing the challenges they faced with this method.

Perceptions of Physics Teaching by Current Teaching Method

1. How many students are in your bachelor-level science education class?
2. Can you share your experience teaching physics and how you approach it in your classroom?
3. Which teaching methods do you prefer the most in physics education, and why?

Benefits of Current Teaching Method

4. What do you see as the strengths of the teaching methods you use in helping students grasp physics concepts?
5. Do you find these methods effective in helping students remember key concepts and formulas?

Elation by Current Teaching Method

6. Can you share a moment when you observed your students achieving a significant breakthrough or understanding a physics concept? What factors contributed to their success?
7. In your experience, what non-cognitive factors, such as enjoyment or curiosity, contribute to creating a positive learning environment in physics?

Motivation by Current Teaching Method

8. Have you noticed any changes in your students' attitudes or motivation towards physics? How would you describe these changes?
9. What motivates you to continue using the teaching methods you apply in your physics classes?

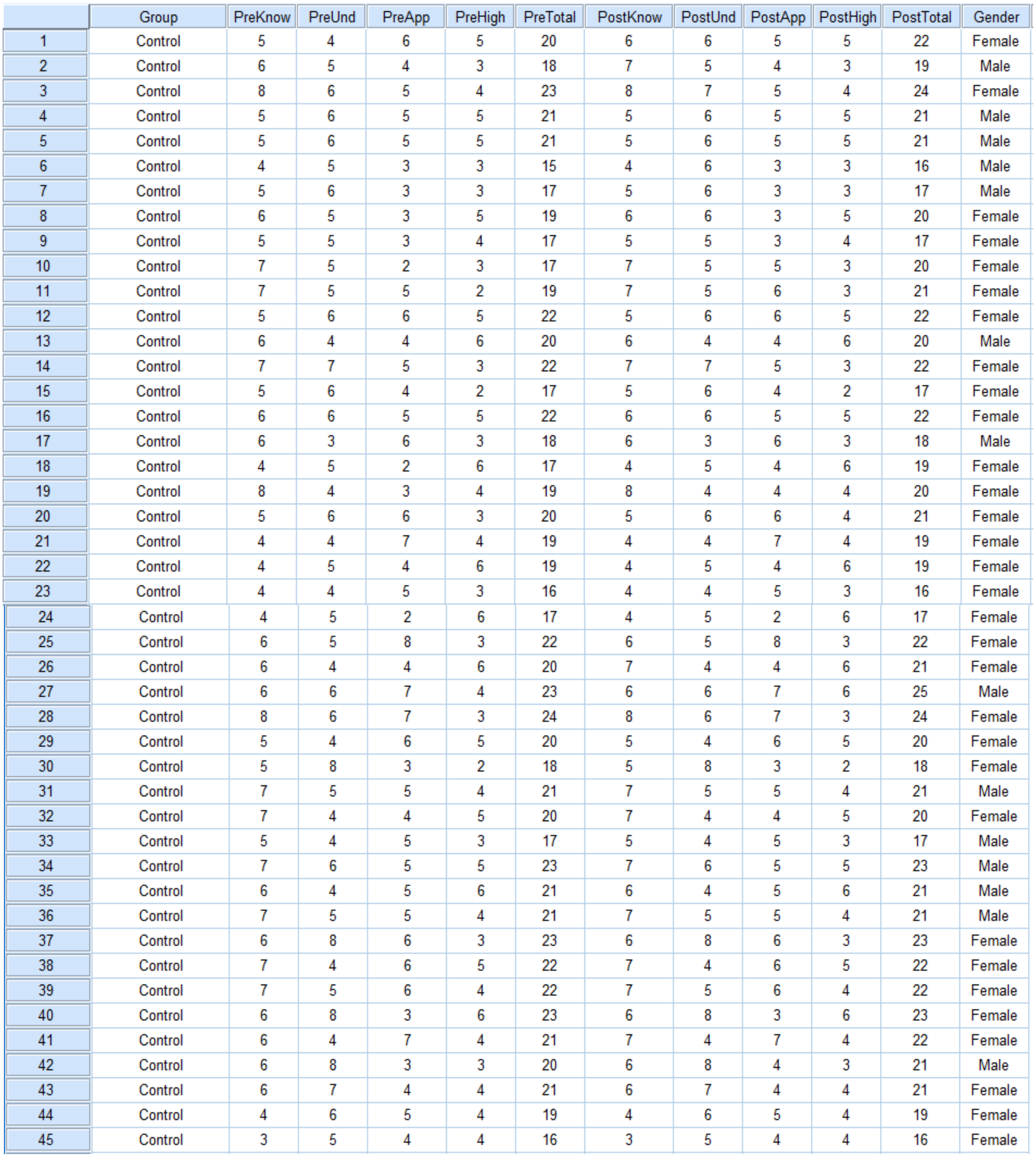
Opportunities by Current Teaching Method

10. How do you think your teaching method influences student interest and engagement in physics?
11. Are there any opportunities you see for enhancing student engagement with physics through the current method? Please explain.

Challenges Faced in Current Teaching Method

12. What challenges have you encountered in teaching physics with your current approach?
13. Have you experienced any difficulties in ensuring student comprehension or engagement? How did you address these challenges?
14. Is there anything you find difficult or limiting about the teaching methods you use in your physics classes?
15. How do you create a positive and engaging classroom environment? How do you keep students motivated and involved in the learning process?

Appendix XVI: Score in Achievement Tests Entry in SPSS Software



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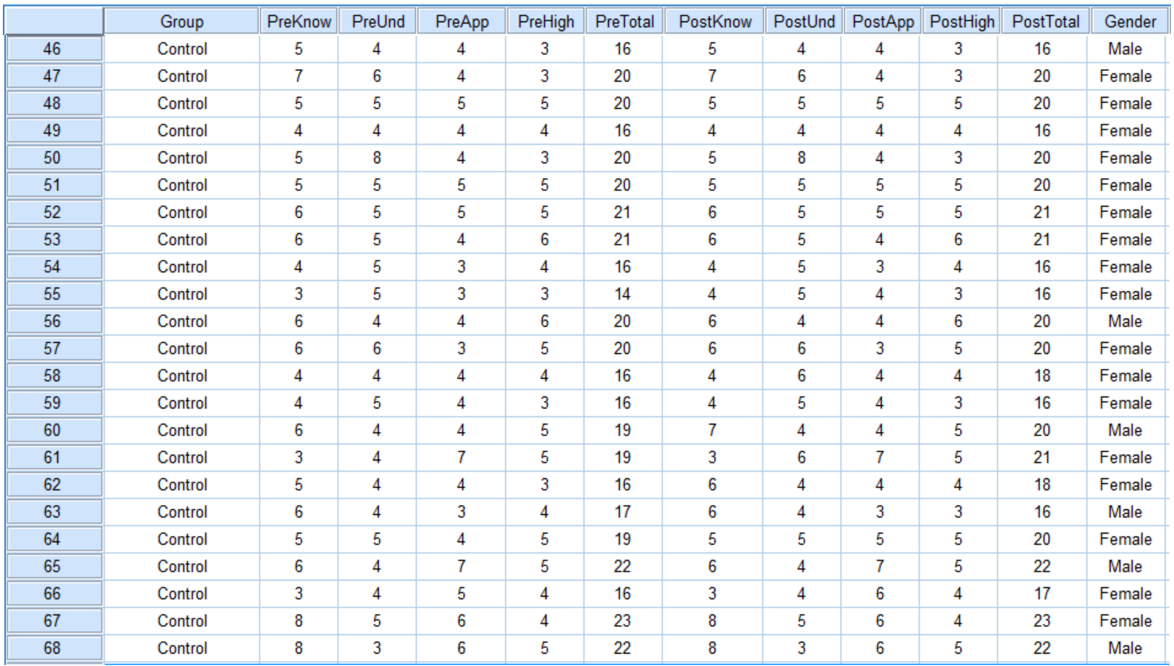

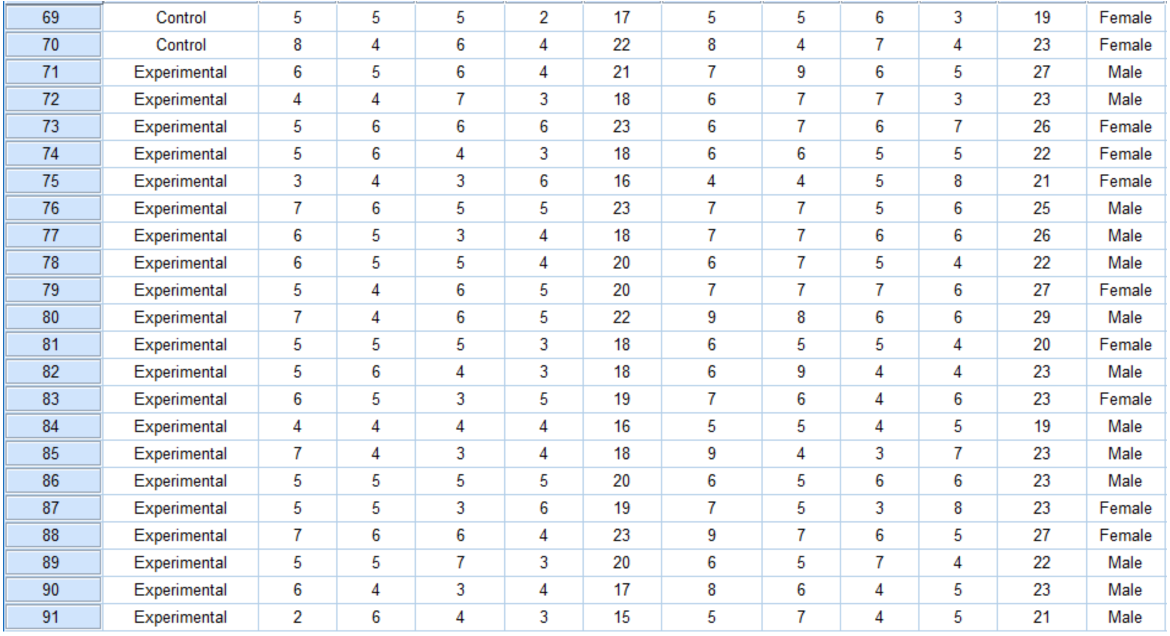

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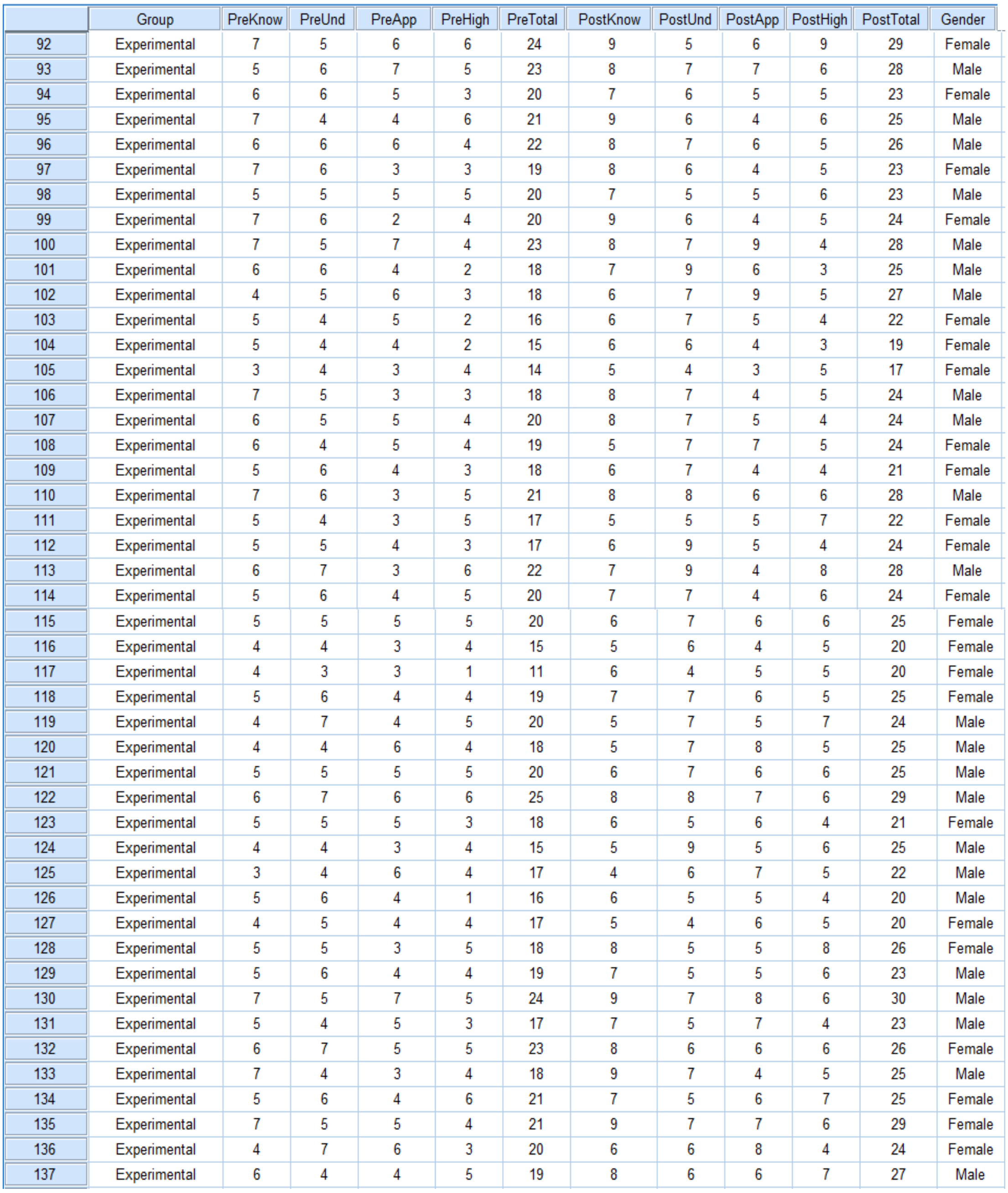

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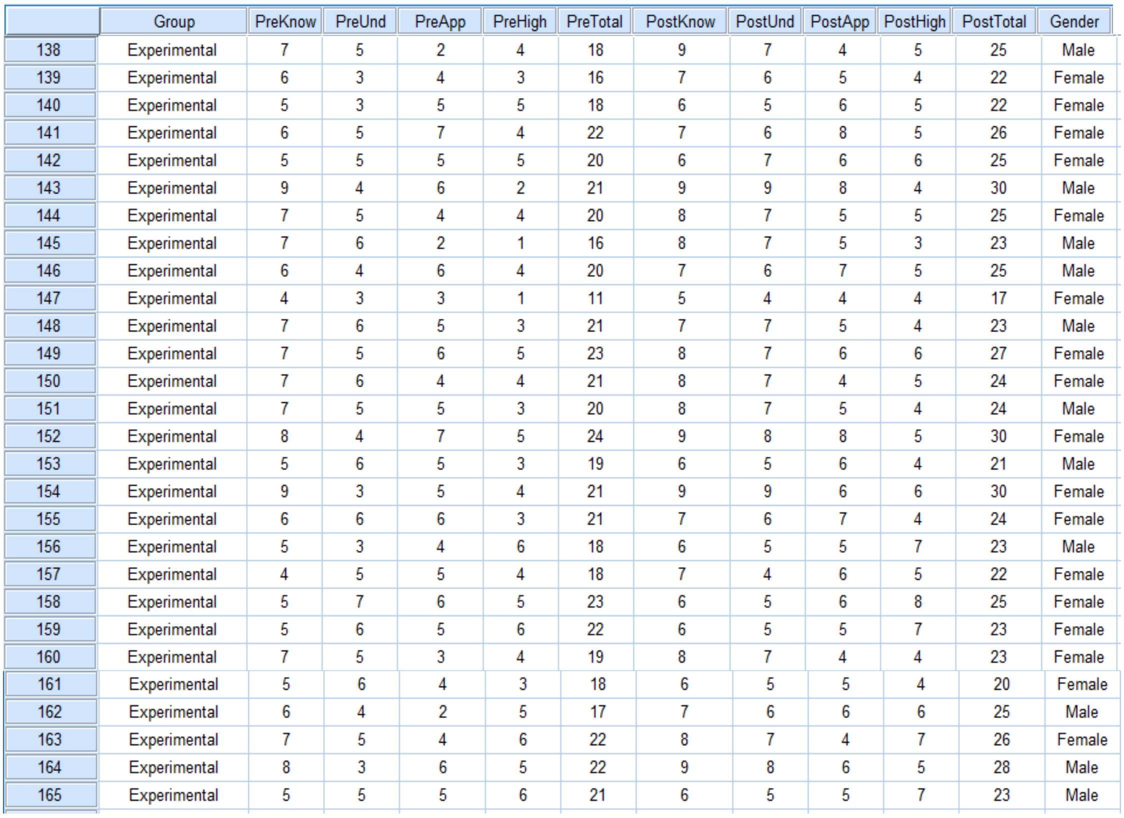


	Group	PreKnow	PreUnd	PreApp	PreHigh	PreTotal	PostKnow	PostUnd	PostApp	PostHigh	PostTotal	Gender
138	Experimental	7	5	2	4	18	9	7	4	5	25	Male
139	Experimental	6	3	4	3	16	7	6	5	4	22	Female
140	Experimental	5	3	5	5	18	6	5	6	5	22	Female
141	Experimental	6	5	7	4	22	7	6	8	5	26	Female
142	Experimental	5	5	5	5	20	6	7	6	6	25	Female
143	Experimental	9	4	6	2	21	9	9	8	4	30	Male
144	Experimental	7	5	4	4	20	8	7	5	5	25	Female
145	Experimental	7	6	2	1	16	8	7	5	3	23	Male
146	Experimental	6	4	6	4	20	7	6	7	5	25	Male
147	Experimental	4	3	3	1	11	5	4	4	4	17	Female
148	Experimental	7	6	5	3	21	7	7	5	4	23	Male
149	Experimental	7	5	6	5	23	8	7	6	6	27	Female
150	Experimental	7	6	4	4	21	8	7	4	5	24	Female
151	Experimental	7	5	5	3	20	8	7	5	4	24	Male
152	Experimental	8	4	7	5	24	9	8	8	5	30	Female
153	Experimental	5	6	5	3	19	6	5	6	4	21	Male
154	Experimental	9	3	5	4	21	9	9	6	6	30	Female
155	Experimental	6	6	6	3	21	7	6	7	4	24	Female
156	Experimental	5	3	4	6	18	6	5	5	7	23	Male
157	Experimental	4	5	5	4	18	7	4	6	5	22	Female
158	Experimental	5	7	6	5	23	6	5	6	8	25	Female
159	Experimental	5	6	5	6	22	6	5	5	7	23	Female
160	Experimental	7	5	3	4	19	8	7	4	4	23	Female
161	Experimental	5	6	4	3	18	6	5	5	4	20	Female
162	Experimental	6	4	2	5	17	7	6	6	6	25	Male
163	Experimental	7	5	4	6	22	8	7	4	7	26	Female
164	Experimental	8	3	6	5	22	9	8	6	5	28	Male
165	Experimental	5	5	5	6	21	6	5	5	7	23	Male

Appendix XVII: Classroom Observations Check List for Students

Scale	Statement	Never		Sometimes	Always	
		1	2	3	4	5
E	Pay attention in class					
E	How will students apply the concept mapping approach to learning?					
E	works nicely with peers					
E	Does he or she behave appropriately around classmates in a classroom setting?					
I	Attempts to achieve his or her work properly and effectively rather than just getting by					
I	Will the student complete their assignment neatly and carefully?					
I	Will he or she perform the tasks as directed?					
D	Acts agitated and is unable to remain seated					
I	Actively participates in discussions					
E	Finishes the assigned seatwork					
D	Reprimand is required					
D	Irritates or interferes with the work of peers					
E	Being tenacious when faced with challenging issues					
N	Doesn't appear to be aware of what is happening in the classroom.					

N	Is reclusive and uncommunicative					
E	Tries sincerely to approach new assignments					
I	Asks inquiries to learn more					
D	Talking excessively with peers					
N	Does not exercise autonomous initiative; requires assistance to begin and continue working.					
E	Tries to complete tasks, regardless of how challenging they are.					
I	Raises his/her hand to provide an answer or information in response to a question					
E	When faced with a challenge in schooling, becomes disheartened and gives up; rapidly becomes frustrated					

Notes: E = Effort; I = Initiative; D = Disruptive behavior; N = Inattentive behavior.

Appendix XVIII: Observation Checklist for Students Reflective Behavior

For each item, select as possible the right answer (score) for yourself taking into account your observation. Tick the appropriate score that shows the degree of the following strategies used.

S.N.	Factors	Not at all	Moderately so		Very much so	
1.	Students creating their own inquiries	1	2	3	4	5
2.	Students' reflections on their learning challenges and misconceptions	1	2	3	4	5
3.	Students classifying and reviewing (interviewing each other, drawing concept maps)	1	2	3	4	5
4.	Students developing or expanding one another's ideas	1	2	3	4	5
5.	Students creating and utilizing marking procedures	1	2	3	4	5
6.	Students diagnosing errors critically	1	2	3	4	5
7.	Students evaluating their own performance against statements of attainment	1	2	3	4	5
8.	Students making performance predictions for themselves	1	2	3	4	5
9.	Students instructing other students	1	2	3	4	5

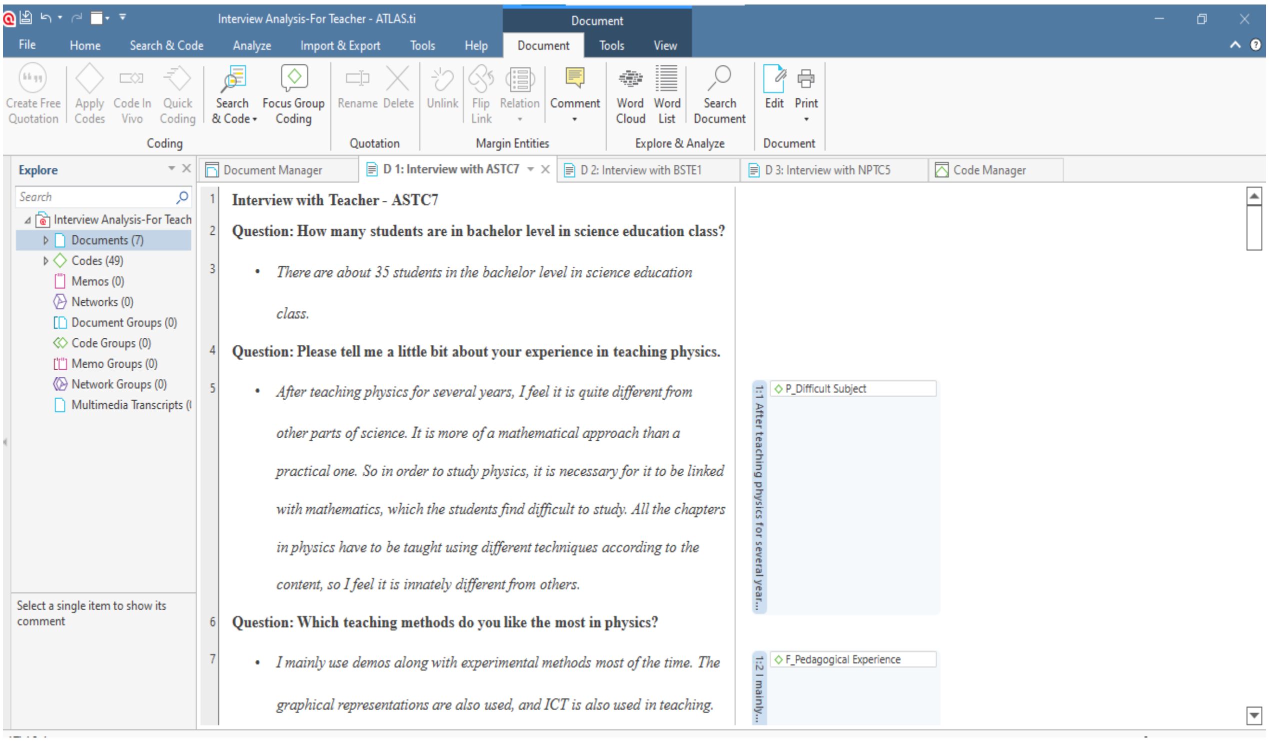
10.	Students are defining physical terms for various physical occurrences.	1	2	3	4	5
11.	Students make use of terms and concepts	1	2	3	4	5
12.	Students making connections between two or more concepts	1	2	3	4	5
13.	Students arranging the concepts	1	2	3	4	5
14.	Students construct prepositions.	1	2	3	4	5
15.	Students conducting mini-debates	1	2	3	4	5
16.	Students engage in peer interactions while working on projects	1	2	3	4	5
17.	Students observing their peers	1	2	3	4	5
18.	Students reflecting how they feel when learning	1	2	3	4	5

Total score ---------------------

....

Signature of observer

Appendix XIX: Qualitative Data Entry in ATLASti.9 Software



1 **Interview with Teacher - ASTC7**

2 **Question: How many students are in bachelor level in science education class?**

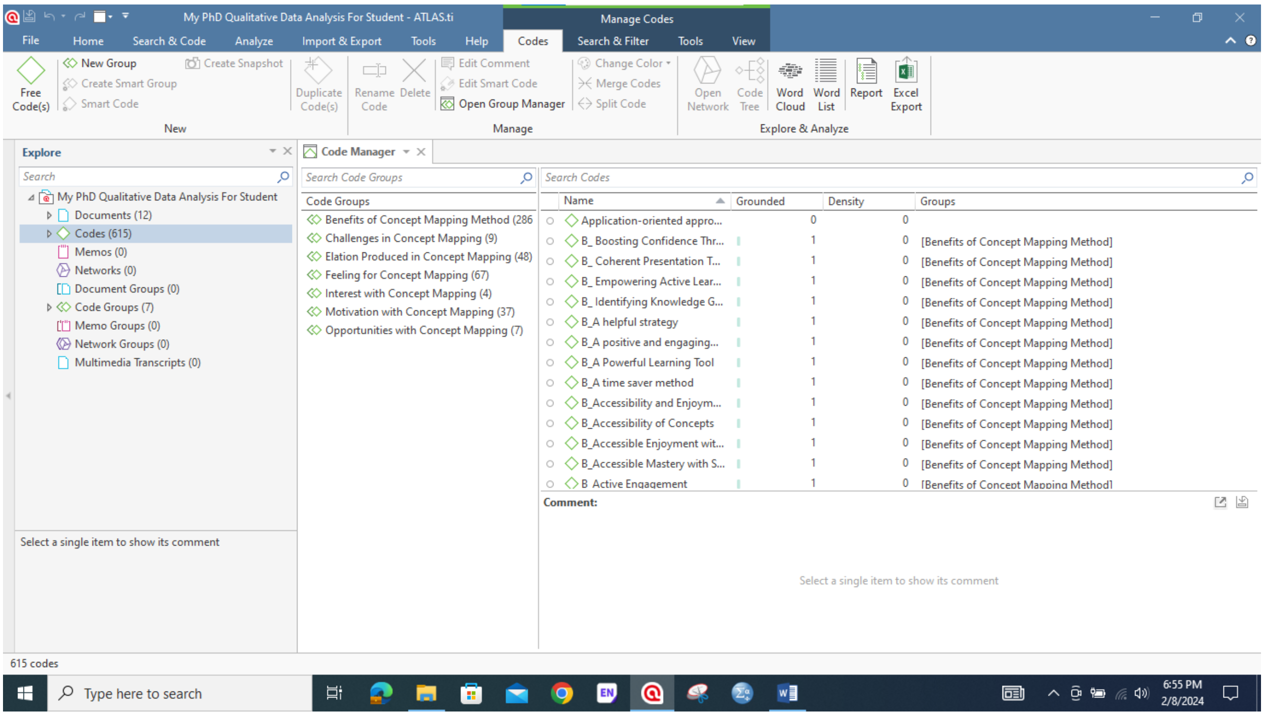
3
- *There are about 35 students in the bachelor level in science education class.*

4 **Question: Please tell me a little bit about your experience in teaching physics.**

5
- *After teaching physics for several years, I feel it is quite different from other parts of science. It is more of a mathematical approach than a practical one. So in order to study physics, it is necessary for it to be linked with mathematics, which the students find difficult to study. All the chapters in physics have to be taught using different techniques according to the content, so I feel it is innately different from others.*

6 **Question: Which teaching methods do you like the most in physics?**

7
- *I mainly use demos along with experimental methods most of the time. The graphical representations are also used, and ICT is also used in teaching.*

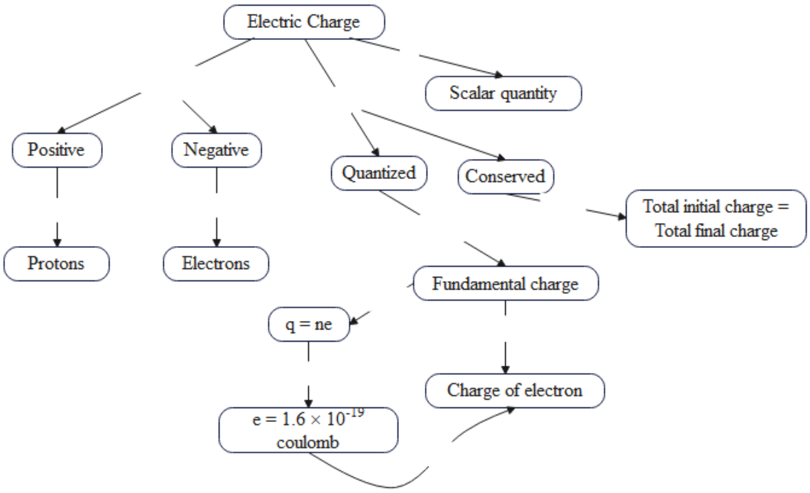


Code Groups
Benefits of Concept Mapping Method (286
Challenges in Concept Mapping (9)
Elation Produced in Concept Mapping (48)
Feeling for Concept Mapping (67)
Interest with Concept Mapping (4)
Motivation with Concept Mapping (37)
Opportunities with Concept Mapping (7)

Name	Grounded	Density	Groups
Application-oriented appro...	0	0	
B_ Boosting Confidence Thr...	1	0	[Benefits of Concept Mapping Method]
B_ Coherent Presentation T...	1	0	[Benefits of Concept Mapping Method]
B_ Empowering Active Lear...	1	0	[Benefits of Concept Mapping Method]
B_ Identifying Knowledge G...	1	0	[Benefits of Concept Mapping Method]
B_A helpful strategy	1	0	[Benefits of Concept Mapping Method]
B_A positive and engaging...	1	0	[Benefits of Concept Mapping Method]
B_A Powerful Learning Tool	1	0	[Benefits of Concept Mapping Method]
B_A time saver method	1	0	[Benefits of Concept Mapping Method]
B_Accessibility and Enjoym...	1	0	[Benefits of Concept Mapping Method]
B_Accessibility of Concepts	1	0	[Benefits of Concept Mapping Method]
B_Accessible Enjoyment wit...	1	0	[Benefits of Concept Mapping Method]
B_Accessible Mastery with S...	1	0	[Benefits of Concept Mapping Method]
B_Active Engagement	1	0	[Benefits of Concept Mapping Method]

Appendix XX: Teacher Generated and Students Generated Concept Maps

Teacher Generated Concept Maps



Students Generated Concept Maps