UNIVERSITY OF DELHI

CNC-II/093/1(25)/2023-24/64
Dated: 30.05.2023

N O T I F I C A T I O N

Sub: Amendment to Ordinance V

[E.C Resolution No. 60/ (60-1-7/) dated 03.02.2023]

Following addition be made to Appendix-II-A to the Ordinance V (2-A) of the Ordinances of the University;

Add the following:

Syllabi of Semester-III of the following departments under Faculty of Mathematical Sciences based on Under Graduate Curriculum Framework -2022 implemented from the Academic Year 2022-23.

FACULTY OF MATHEMATICAL SCIENCES

DEPARTMENT OF COMPUTER SCIENCE

BSC. (HONS.) COMPUTER SCIENCE

DISCIPLINE SPECIFIC CORE COURSE -7 (DSC-7) : Data Structures

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC07 Data Structures	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	Programming using Python/Object Oriented Programming with C++

Learning Objectives

The course aims at developing the ability to use basic data structures like arrays, stacks, queues, lists, and trees to solve problems. C++ is chosen as the language to implement the implementation of these data structures.

Learning outcomes

On successful completion of the course, students will be able to:

- Compare two functions for their rates of growth.
- Understand abstract specification of data-structures and their implementation.
- Compute time and space complexity of operations on a data-structure.
- Identify the appropriate data structure(s) for a given application and understand the trade-offs involved in terms of time and space complexity.
- Apply recursive techniques to solve problems.

SYLLABUS OF DSC-7

Unit 1 (9 hours)

Growth of Functions, Recurrence Relations: Functions used in analysis, asymptotic notations, asymptotic analysis, solving recurrences using recursion trees, Master Theorem.

Unit 2 (16 hours)

Arrays, Linked Lists, Stacks, Queues: Arrays: array operations, applications, two-dimensional arrays, dynamic allocation of arrays; Linked Lists: singly linked lists, doubly linked lists, circularly linked lists, Stacks: stack as an ADT, implementing stacks using arrays, implementing stacks using linked lists, applications of stacks; Queues: queue as an ADT, implementing queues using arrays, implementing queues using linked lists,. Time complexity analysis.

Unit 3 (5 hours)

Recursion: Recursive functions, linear recursion, binary recursion.

Unit 4 (6 hours)

Trees, Binary Trees: Trees: definition and properties, tree traversal algorithms, and their time complexity analysis; binary trees: definition and properties, traversal of binary trees, and their time complexity analysis.

Unit 5 (7 hours)

Binary Search Trees, Balanced Search Trees: Binary Search Trees: insert, delete, search operations, time complexity analysis of these operations; Balanced Search Trees: insert, search operations, time complexity analysis of these operations. Time complexity analysis.

Unit 6 (2 hours)

Binary Heap: Binary Heaps: heaps, heap operations.

Essential/recommended readings

1. Goodrich, M.T., Tamassia, R., & Mount, D., *Data Structures and Algorithms Analysis in C++,* 2nd edition, Wiley, 2011.
2. Cormen, T.H., Leiserson, C.E., Rivest, R. L., Stein C. *Introduction to Algorithms*, 4th edition, Prentice Hall of India, 2022.

Additional references

1. Sahni, S. *Data Structures, Algorithms and applications in C++*, 2nd edition, Universities Press, 2011.
2. Langsam Y., Augenstein, M. J., & Tanenbaum, A. M. *Data Structures Using C and C++*, Pearson, 2009.

Practical List (If any): (30 Hours)

Practical exercises such as

1. Write a program to implement singly linked list as an ADT that supports the following operations:
   (i) Insert an element x at the beginning of the singly linked list
   (ii) Insert an element x at i^{th} position in the singly linked list
   (iii) Remove an element from the beginning of the singly linked list
   (iv) Remove an element from i^{th} position in the singly link
   (v) Search for an element x in the singly linked list and return its pointer
   (vi) Concatenate two singly linked lists

2. Write a program to implement doubly linked list as an ADT that supports the following operations:
   (i) Insert an element x at the beginning of the doubly linked list
   (ii) Insert an element x at i^{th} position in the doubly linked list
   (iii) Insert an element x at the end of the doubly linked list
   (iv) Remove an element from the beginning of the doubly linked list
   (v) Remove an element from i^{th} position in the doubly linked list.
   (vi) Remove an element from the end of the doubly linked list
   (vii) Search for an element x in the doubly linked list and return its pointer
   (viii) Concatenate two doubly linked lists

3. Write a program to implement circular linked list as an ADT which supports the following operations:
   (i) Insert an element x at the front of the circularly linked list
   (ii) Insert an element x after an element y in the circularly linked list
   (iii) Insert an element x at the back of the circularly linked list
   (iv) Remove an element from the back of the circularly linked list
   (v) Remove an element from the front of the circularly linked list
   (vi) Remove the element x from the circularly linked list
   (vii) Search for an element x in the circularly linked list and return its pointer

(viii) Concatenate two circularly linked lists

4. Implement a stack as an ADT using Arrays.

5. Implement a stack as an ADT using the Linked List ADT.

6. Write a program to evaluate a prefix/postfix expression using stacks.

7. Implement Queue as an ADT using the circular Arrays.

8. Implement Queue as an ADT using the Circular Linked List ADT.

9. Write a program to implement Binary Search Tree as an ADT which supports the following operations:
   (i) Insert an element x
   (ii) Delete an element x
   (iii) Search for an element x in the BST and change its value to y and then place the node with value y at its appropriate position in the BST
   (iv) Display the elements of the BST in preorder, inorder, and postorder traversal
   (v) Display the elements of the BST in level-by-level traversal
   (vi) Display the height of the BST

10. Write a program to implement a balanced search tree as an ADT.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 8 (DSC-8): Operating Systems

Credit distribution, Eligibility and Prerequisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC 08 Operating Systems	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	Programming using Python/Object Oriented Programming with C++, Computer System Architecture

Learning Objectives

The course provides concepts that underlie all operating systems and are not tied to any particular operating system. The emphasis is on explaining the need and structure of an operating system using its common services such as process management (creation, termination etc.), CPU Scheduling, Process Synchronization, Handling Deadlocks, main memory management, virtual memory, secondary memory management. The course also introduces various scheduling algorithms, structures, and techniques used by operating systems to provide these services.

Learning outcomes

On successful completion of the course, students will be able to:

- Describe the need of an operating system and define multiprogramming and Multithreading concepts.
- Implement the process synchronization service (Critical Section, Semaphores), CPU scheduling service with various algorithms.
- Implement Main memory Management (Paging, Segmentation) algorithms, Handling of Deadlocks
- Identify and appreciate the File systems Services, Disk Scheduling service

SYLLABUS OF DSC-8

Unit 1 (6 hours)

Introduction: Operating Systems (OS) definition and its purpose, Multiprogrammed and Time Sharing Systems, OS Structure, OS Operations: Dual and Multi-mode, OS as resource manager.

Unit 2 (9 hours)

Operating System Structures: OS Services, System Calls: Process Control, File Management, Device Management, and Information Maintenance, Inter-process Communication, and Protection, System programs, OS structure- Simple, Layered, Microkernel, and Modular.

Unit 3 (10 hours)

Process Management: Process Concept, States, Process Control Block, Process Scheduling, Schedulers, Context Switch, Operation on processes, Threads, Multicore Programming, Multithreading Models, PThreads, Process Scheduling Algorithms: First Come First Served, Shortest-Job-First, Priority & Round-Robin, Process Synchronization: The critical-section problem and Peterson's Solution, Deadlock characterization, Deadlock handling.

Unit 4 (11 hours)

Memory Management: Physical and Logical address space, Swapping, Contiguous memory allocation strategies - fixed and variable partitions, Segmentation, Paging.
Virtual Memory Management: Demand Paging and Page Replacement algorithms: FIFO Page Replacement, Optimal Page replacement, LRU page replacement.

Unit 5 (9 hours)

File System: File Concepts, File Attributes, File Access Methods, Directory Structure: Single-Level, Two-Level, Tree-Structured, and Acyclic-Graph Directories.
Mass Storage Structure: Magnetic Disks, Solid-State Disks, Magnetic Tapes, Disk Scheduling algorithms: FCFS, SSTF, SCAN, C-SCAN, LOOK, and C-LOOk Scheduling.

Essential/recommended readings

1. Silberschatz, A., Galvin, P. B., Gagne G. *Operating System Concepts,* 9th edition, John Wiley Publications, 2016.
2. Tanenbaum, A. S. *Modern Operating Systems*, 3rd edition, Pearson Education, 2007.
3. Stallings, W. *Operating Systems: Internals and Design Principles,* 9th edition, Pearson Education, 2018.

Additional References

1. Dhamdhere, D. M., *Operating Systems: A Concept-based Approach,* 2nd edition, Tata McGraw-Hill Education, 2017.
2. Kernighan, B. W., Rob Pike, R. *The Unix Programming Environment*, Englewood Cliffs, NJ: Prentice-Hall, 1984.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

1. Execute various Linux commands for:
   i. Information Maintenance: wc, clear, cal, who, date, pwd
   ii. File Management: cat, cp, rm, mv, cmp, comm, diff, find, grep, awk
   iii. Directory Management : cd, mkdir, rmdir, ls
2. Execute various Linux commands for:
   i. Process Control: fork, getpid, ps, kill, sleep
   ii. Communication: Input-output redirection, Pipe
   iii. Protection Management: chmod, chown, chgrp
3. Write a programme (using fork() and/or exec() commands) where parent and child execute:
   i. same program, same code.
   ii. same program, different code.
   iii. Before terminating, the parent waits for the child to finish its task.
4. Write a program to to report behaviour of Linux kernel including kernel version, CPU type and model. (CPU information)

5. Write a program to report behaviour of Linux kernel including information on 19 configured memory, amount of free and used memory. (Memory information)
6. Write a program to copy files using system calls.
7. Use an operating system simulator to simulate operating system tasks.
8. Write a program to implement scheduling algorithms FCFS/ SJF/ SRTF/ non-preemptive scheduling algorithms.
9. Write a program to calculate the sum of n numbers using Pthreads. A list of n numbers is divided into two smaller lists of equal size, and two separate threads are used to sum the sublists.
10. Write a program to implement first-fit, best-fit and worst-fit allocation strategies.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE– 9 (DSC-9): Numerical Optimization

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC09 Numerical Optimization	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	Programming using Python/Object Oriented Programming with C++

Learning Objectives

The course aims to provide students with the experience of mathematically formulating a large variety of optimization/decision problems emerging out of various fields like data science, machine learning, business, and finance. The course focuses on learning techniques to optimize problems in order to obtain the best possible solution.

Learning outcomes

At the end of the course, students will be able to:

- Mathematically formulate the optimization problems using the required number of independent variables.
- Define constraint functions on a problem.
- Check the feasibility and optimality of a solution.
- Apply conjugate gradient method to solve the problem.

SYLLABUS OF DSC-9

Unit 1 (6 hours)

Introduction: Mathematical Formulation using example, Continuous versus Discrete Optimization, Constrained and Unconstrained Optimization, Global and Local Optimization, Stochastic and Deterministic Optimization, Convexity, Optimization Algorithms

Unit 2 (14 hours)

Fundamentals of Unconstrained Optimization: Concept of a Solution - Recognizing a Local Minimum, Nonsmooth Problems, Overview of Algorithms - Two Strategies: Line Search and Trust Region, Search Directions for Line Search Methods, Models for Trust-Region Methods, Scaling. Line Search - Convergence of Line Search Methods, Rate of Convergence - Convergence Rate of Steepest Descent; Newton's Method, Quasi-Newton Methods. Trust Region - The Cauchy Point Algorithm; Global Convergence - Reduction Obtained by the Cauchy Point; Convergence to Stationary Points.

Unit 3 (7 hours)

Conjugate Gradient Methods: Basic Properties of the Conjugate Gradient Method, A Practical Form of the Conjugate Gradient Method, and Rate of Convergence

Unit 4 (8 hours)

Calculating Derivatives: Finite-Difference Derivative Approximations, Approximating the Gradient, Approximating a Sparse Jacobian, Approximating the Hessian, Approximating a Sparse Hessian

Unit 5 (10 hours)

Theory of Constrained Optimization: Local and Global Solutions, Smoothness, Examples - A Single Equality Constraint, A Single Inequality Constraint, Two Inequality Constraints, Tangent Cone and Constraint Qualifications, First-Order Optimality Condition, Second-Order Conditions - Second-Order Conditions and Projected Hessians. Linear and non-linear constrained optimization, augmented Lagrangian Method

Essential/recommended readings

1. J. Nocedal and S.J. Wright, *Numerical Optimization*, 2nd edition, Springer Series in Operations Research, 2006.
2. A, Mehra, S Chandra, Jayadeva, *Numerical Optimization with Applications*, Narosa Publishing House, New Delhi, 2009,

Additional References

1. R. W. Hamming, *Numerical Methods for Scientists and Engineers,* 2nd edition, Dover Publications, 1986.
2. Q. Kong, T. Siauw, A. Bayen, *Python Programming and Numerical Methods: A Guide for Engineers and Scientists,* 1st edition, 2020.

Suggested Practical List (If any) :(30 Hours)

Practical exercises such as

Write a program to implement the following methods:

Constrained and Unconstrained Optimization, Global and Local Optimization, Line Search and Trust Region, Convergence of Line Search Methods, Rate of Convergence - Convergence Rate of Steepest Descent, Newton's Method, Quasi-Newton Methods, The Cauchy Point algorithm, Finite-Difference Derivative Approximations, Convergence to Stationary Points, Conjugate Gradient Method, Rate of Convergence, Approximating a Sparse Jacobian, Approximating the Hessian, Approximating a Sparse Hessian, First-Order Optimality Condition, Second-Order Conditions - Second-Order Conditions, and Projected Hessians. Linear and non-linear constrained optimization Augmented Lagrangian Methods.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Computer Science Courses for Undergraduate Programme of study with Computer Science discipline Elective

DISCIPLINE SPECIFIC ELECTIVE COURSE: Data Analysis and Visualization

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Data Analysis and Visualization (DAV)	**4**	**3**	**0**	**1**	**Pass in XII class**	Programming using Python/ Class XI-XII Computer Science/ Class XI-XII Informatics Practices

Learning Objectives

This course is designed to introduce the students to real-world data analysis problems, the use of statistics to get a deterministic view of data, and interpreting results in the field of exploratory data science using Python. This course is the first in the "Data Science" pathway and builds the foundation for three subsequent courses in the pathway.

Learning outcomes

On successful completion of the course, students will be able to:

1. Apply descriptive statistics to obtain a deterministic view of data
2. Perform data handling using Numpy arrays
3. Load, clean, transform, merge, and reshape data using Pandas
4. Visualize data using Pandas and matplot libraries
5. Solve real world data analysis problems

SYLLABUS OF DSE

Unit 1 (10 hours)

Introduction to basic statistics and analysis: Fundamentals of Data Analysis, Statistical foundations for Data Analysis, Types of data, Descriptive Statistics, Correlation and covariance, Linear Regression, Statistical Hypothesis Generation and Testing, Python Libraries: NumPy, Pandas, Matplotlib

Unit 2 (8 hours)

Array manipulation using Numpy: Numpy array: Creating Numpy arrays; various data types of Numpy arrays, indexing and slicing, swapping axes, transposing arrays, data processing using Numpy arrays.

Unit 3 (12 hours)

Data Manipulation using Pandas: Data Structures in Pandas: Series, DataFrame, Index objects, Loading data into Pandas data frame, Working with DataFrames: Arithmetics, Statistics, Binning, Indexing, Reindexing, Filtering, Handling missing data, Hierarchical indexing, Data wrangling: Data cleaning, transforming, merging and reshaping

Unit 4 (8 hours)

Plotting and Visualization: Using Matplotlib to plot data: figures, subplots, markings, color and line styles, labels and legends, Plotting functions in Pandas: Line, bar, Scatter plots, histograms, stacked bars, Heatmap

Unit 5 (7 hours)

Data Aggregation and Group operations: Group by mechanics, Data aggregation, General split-apply-combine, Pivot tables and cross tabulation

Essential/recommended readings

1. McKinney W. *Python for Data Analysis: Data Wrangling with Pandas, NumPy and IPython*, 2nd edition, O'Reilly Media, 2018.
2. Molin S. *Hands-On Data Analysis with Pandas*, Packt Publishing, 2019.
3. Gupta S.C., Kapoor V.K. *Fundamentals of Mathematical Statistics*,12th edition, Sultan Chand & Sons, 2020.

Additional References

1. Chen D. Y. *Pandas for Everyone: Python Data Analysis*, First edition, Pearson Education, 2018.
2. Miller J.D. *Statistics for Data Science,* Packt Publishing Limited, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

Use a dataset of your choice from Open Data Portal (https:// data.gov.in/, UCI repository) or load from scikit, seaborn library for the following exercises to practice the concepts learnt.

1. Load a Pandas dataframe with a selected dataset. Identify and count the missing values in a dataframe. Clean the data after removing noise as follows
   a) Drop duplicate rows.
   b) Detect the outliers and remove the rows having outliers
   c) Identify the most correlated positively correlated attributes and negatively correlated attributes

2. Import iris data using sklearn library or (Download IRIS data from: https://archive.ics.uci.edu/ml/datasets/iris or import it from sklearn.datasets)
    i. Compute mean, mode, median, standard deviation, confidence interval and standard error for each feature
    ii. Compute correlation coefficients between each pair of features and plot heatmap
    iii. Find covariance between length of sepal and petal
    iv. Build contingency table for class feature

3. Load Titanic data from sklearn library , plot the following with proper legend and axis labels:

    a. Plot bar chart to show the frequency of survivors and non-survivors for male and female passengers separately
    b. Draw a scatter plot for any two selected features
    c. Compare density distribution for features age and passenger fare
    d. Use a pair plot to show pairwise bivariate distribution

4. Using Titanic dataset, do the following
    a. Find total number of passengers with age less than 30
    b. Find total fare paid by passengers of first class
    c. Compare number of survivors of each passenger class

5. Download any dataset and do the following
    a. Count number of categorical and numeric features
    b. Remove one correlated attribute (if any)
    c. Display five-number summary of each attribute and show it visually

Project: Students are encouraged to work on a good dataset in consultation with their faculty and apply the concepts learned in the course.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE: Microprocessors

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Microprocessors	**4**	**3**	**0**	**1**	**Pass in XII class**	Computer System Architecture

Learning Objectives

This course introduces the internal architecture, programming models of Intel Microprocessors (8086 - Pentium) and assembly language programming. Students will also learn interfacing of memory and I/O devices with microprocessors.

Learning outcomes

On successful completion of the course, students will be able to:

- Describe the internal architecture of Intel microprocessors.
- Define and implement interfaces between the microprocessor and the devices.
- Write assembly language programs.

SYLLABUS OF DSE

Unit 1 (5 hours)

Microprocessor Architecture: Internal Architecture, Programming Model, Addressing Modes, Data Movement Instructions

Unit 2 (7 hours)

Microprocessor programming: Register Organization, instruction formats, Program control instructions, assembly language.

Unit 3 (10 hours)

Interfacing: Bus timings, Memory address decoding, cache memory and cache controllers, I/O interface, keyboard, timer, Interrupt controller, DMA controller, video controllers, communication interfaces.

Unit 4 (7 hours)

Data transfer schemes: Synchronous data transfer, asynchronous data transfer, interrupt driven data transfer, DMA mode data transfer.

Unit 5 (8 hours)

Microprocessor controllers: I/O controllers, interrupt controller, DMA controller, USART controller.

Unit 6 (8 hours)

Advanced microprocessor architecture: CISC architecture, RISC architecture, superscalar architecture, multicore architecture.

Essential/recommended readings

1. Brey, B.B. *The Intel Microprocessors: Architecture, Programming and Interfacing,* 8th edition, Pearson education, 2009.

2. Triebel, W.A., & Singh, A. *The 8088 and 8086 Microprocessors Programming, Interfacing, Software, Hardware and Applications*, 4th edition, Pearson education, 2002.

Additional References

1. Ramesh S Gaonkar *Microprocessor architecture, programming, and applications with the 8085,* 6th edition, Penram International Publishing, 2013.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

ASSEMBLY LANGUAGE PROGRAMMING

1. Write a program to print 'Hello World'.
2. Write a program to print two strings on two different lines.
3. Write a program to take a single digit number from the user and print that number on the console.
4. Write a program to compare two single digit numbers and check if they are equal or not.
5. Write a program for 8-bit addition of two single digit numbers. Show the result after ASCII adjust.
6. Write a program for 16-bit addition of two double digit numbers. Show the result after ASCII adjust.
7. Write a program for 16-bit BCD addition.
8. Write a program for 32-bit BCD addition and subtraction.
9. Write a program for 32-bit Binary addition,subtraction,multiplication and division.
10. Write a program for Binary to ASCII conversion.
11. Write a program for ASCII to Binary conversion.
12. Write a program to take input in an array and print it on the console.
13. Write a program to sort an array using bubble sort.
14. Write a program to perform linear search in an array.
15. Write a program to perform binary search in an array.
16. Write a program to add and subtract two arrays.
17. write programs to interface a microprocessor with external devices such as a keyboard and elevator.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

(Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the three Core Disciplines)

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE 01a PYTHON Programming for Data Handling	**4**	**3**	**0**	**1**	Pass in Class XII	NIL

Learning Objectives

The course introduces students to the concept of data handling using files and GUI designing. This would equip the students with knowledge to work on real world data from various applications and GUI development for effective data handling.

Learning outcomes

On successful completion of the course, students will be able to:

- Learn constructs of Python language
- Perform data handling with files using Python.
- Design and implement GUI applications using Tkinter.

SYLLABUS OF DSE 01a

Unit 1 (15 Hours)

Introduction to Python Programming, Basic Constructs, and Python Built-in Data Structures: Introduction to Python programming language, Basic syntax, variables, and data

types in Python, Functions and modular programming; Conditional statements (if, elif, else); Looping structures (for and while loops); Mutable and Immutable Data Structures, Strings-Indexing, slicing, traversal, operations; Lists-indexing, slicing, traversal, operations; tuples, dictionaries, and sets and their operations in Python

Unit 2 (5 Hours)

File Handling: Opening, reading, writing, and closing files; File modes and file object methods; Reading and writing text and binary files; Working with CSV files

Unit 3 (15 Hours)

Designing GUI Applications with Tkinter (15): What is Tkinter? Creating a Tkinter window, Layout managers, Tkinter widgets -Entry, Spinbox, Combobox, Checkbutton, Text, Button, LabelFrame; Implementing the application - LabelInput class, building of form, adding LabelFrame and other widgets, retrieving data from form, resetting form, building our application class.

Unit 4 (10 Hours)

Combining Python file handling and Tkinter: Creating a simple Tkinter application, Reading and writing to csv files in a Tkinter application

Essential/recommended readings

1. Taneja S., Kumar, N. Python Programming- A modular approach, 1st Edition, Pearson Education India, 2018,

2. Moore, Alan D. Python GUI Programming with Tkinter: Develop responsive and powerful GUI applications with Tkinter. Packt Publishing Ltd, 2021.

Additional References:

1. Guttag, J.V. Introduction to computation and programming using Python, 2nd edition, MIT

Online references/material:

1. https://docs.python.org/3/library/csv.html

Suggested Practical List (If any): (30 Hours)

Installing and setting up Python and relevant libraries; Python development environments (e.g., Anaconda, Jupyter Notebook)

1. Write a Python program to calculate the factorial of a number.
2. Write a Python program to generate prime numbers between 1 to n, where n is provided as input by the user.
3. Write a Python program to find the sum and average of numbers in a given list.
4. Given two sets, set1 and set2, write a Python program to find their union, intersection and difference.
5. Given a list of numbers, write a Python program to count the number of times an element occurs in a list and create a dictionary with *element:count* as *key:value* pairs.
6. Write a Python program to swap the first two and last two characters in a given string.
7. Write a Python program to create a text file having names of ten Indian cities.
8. Write a Python program to create a text file having atleast five lines about your college using `writelines()` function.
9. Write a Python program which reads the data from three input files having Employee Names and merges them into one output file.
10. Write a Python program to count the number of vowels in a file and write the *vowel : count* in a dictionary.
11. Write a Python program to create a CSV file having student data: RollNo, Enrollment No, Name, Course, Semester.
12. Write a Python program library to read the CSV file created in the above program and filter out records of II semester students.
13. Write a Python program using tkinter library to create a GUI to enter registration details for an event.
14. Write a Python program using tkinter library to create a calculator to perform addition, subtraction, multiplication and division of two numbers entered by the user.
15. Write a Python program using tkinter library to create an age calculator to calculate age when DOB is entered.
16. Write a Python program using tkinter library to read and write student data to and from a CSV file (refer question 11).

Note: **Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.**

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Android Programming using Java	**4**	**3**	**0**	**1**	Pass in Class XII	NIL

Learning Objective

The course enables the students to understand Android architecture and its key features, making them competent to develop Android applications using Java.

Learning outcomes

On successful completion of the course, students will be able to:

- logically organize Java classes and interfaces using packages.
- understand the design of the Android operating system.
- design user interfaces using various dialog boxes, menus, etc.
- design Android applications with interaction among various activities/applications.

SYLLABUS OF DSE 01b

Unit 1 (15 hours)
Review of Object Oriented Programming and Java Fundamentals: Structure of Java programs, classes and objects, data types, type casting, looping constructs, inheritance.

Unit 2 (2 hours)
Interfaces: Interface basics, defining, implementing and extending interfaces.

Unit 3 (4 hours)
Packages: Basics of packages, creating and accessing packages.

Unit 4 (7 hours)
GUI Programming: AWT classes, event handling.

Unit 5 (5 hours)

Introduction to Android Programming: Introduction to Android Operating System, Android SDK, AVD, components of an Android Application, parcels, and bundles.

Unit 6 (6 hours)

User Interface Architecture: Android Architecture, Contexts in Android, Intents and Intent Filters, Activity Life Cycle, Activity Stack, Fragments, and Fragments Life Cycle.

Unit 7 (6 hours)

User Interface Design: Android Layouts, Views, Spinner, Menu, Toggle Buttons, Radio Buttons, Check Boxes, Alert Box, and Toasts.

Essential/recommended readings

1. Schildt H. Java: The Complete Reference. 12th edition. McGraw-Hill Education, 2021
2. Griffiths D. & Griffiths D. Head First Android Development. O'Reilly, 2017
3. Meier R. Professional AndroidTM 4 Application Development. John Wiley & Sons, Inc., 2012

Additional Resources:

1. Horstmann, C. S. Core Java - Vol. I – Fundamentals. 12th edition. Pearson Education, 2021
2. Murphy M. L. The Busy Coder's Guide to Android Development. CommonsWare, 2018
3. Phillips B., Stewart C., Hardy B. & Marsicano K. Android Programming: The Big Nerd Ranch Guide. Big Nerd Ranch, LLC, 2015
4. Sheusi J. C. Android Application Development for Java Programmers. Cengage Learning, 2013

Suggested Practical List (If any): (30 Hours)

1. Write a function to find whether a number is prime or not. Use this function to determine the nth prime number. Read n from the user.

2. Design a class Complex having a real part (x) and an imaginary part (y). Provide methods to perform the following on complex numbers:

    a. Add two complex numbers.

b. Multiply two complex numbers.

c. toString() method to display complex numbers in the form: x + i y

3. Create a class TwoDim which contains private members as x and y coordinates in package P1. Define the default constructor, a parameterized constructor and override toString() method to display the co-ordinates. Now reuse this class and in package P2 create another class ThreeDim, adding a new dimension as z as its private member. Define the constructors for the subclass and override toString() method in the subclass also. Write appropriate methods to show dynamic method dispatch. The main() function should be in a package P.

4. Write a program to create an Applet. Create a frame as a child of an applet. Implement mouseClicked( ), mouseEntered( ) and mouseExited( ) events for the applet. Frame is visible when mouse enters applet window and hidden when mouse exits from the applet window.

5. Write a program to display a string in a frame window with pink color as background.

6. Write a program to create an Applet that has two buttons named “Red” and “Blue”. When a button is pressed, the background color of the applet is set to the color named by the button’s label.

7. Create a “Hello World” application. That will display “Hello World” in the middle of the screen in the emulator. Also display “Hello World” in the middle of the screen in the Android Phone.

8. Create an Android application with a login module. (Check username and password).

9. Create a Spinner with strings taken from resource folder (res >> value folder) and on changing the spinner value, Image will change.

10. Create a Menu with 5 options and a selected option should appear in the text box.

11. Create an application with three option buttons, on selecting a button colour of the screen will change.

12. Create an Application to display various Activity and Fragment Life Cycle Methods.

13. Create an application with 2 fragments, one to set the background and other to set the fore-color of the text.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES

GENERIC ELECTIVES : Database Management Systems

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course	Department offering the course
		Lecture	Tutorial	Practical/ Practice			
Database Management Systems	**4**	**3**	**0**	**1**	**Pass in class XII**	NIL	**Computer Science**

Learning Objectives

The course introduces the students to the fundamentals of database management systems and their applications. Emphasis is given to the popular relational database system. Students will learn about the importance of database structure and its design using entity relationship diagrams and a formal approach using normalization. Basic concepts of file indexing and transaction processing will be taught. The course would give students hands-on practice with structured query language to create, manipulate, and implement a relational database.

Learning outcomes

On successful completion of the course, students will be able to:

- Use relational database management software to create and manipulate the database.
- Create conceptual data models using entity relationship diagrams for modeling real-life situations and map it to corresponding relational database schema.
- Use the concept of functional dependencies to remove redundancy and update anomalies.
- Apply normalization theory to get a normalized database scheme to get anomalies free databases.
- Write queries in relational algebra.
- Implement relational databases and formulate queries for data retrieval and data update problems using SQL.
- Learn the importance of index structures and concurrent execution of transactions in database systems.

SYLLABUS

Unit 1 (5 hours)

Introduction to Database: Database, characteristics of database approach, data models, database management system, three-schema architecture, components of DBMS, data independence, and file system approach vs. database system approach

Unit 2 (8 hours)

Entity Relationship Modeling: Conceptual data modeling - motivation, entities, entity types, attributes, relationships, relationship types, constraints on relationship, Entity Relationship diagram as conceptual data model.

Unit 3 (11 hours)

Relational Data Model: Data anomalies, Relational Data Model - Characteristics of a relation, schema-instance distinction, types of keys, relational integrity constraints. Relational algebra operators like selection, projection, cartesian product, join and write simple queries using them.

Unit 4 (10 hours)

Structured Query Language (SQL): DDL to create database and tables, table constraints, DML, Querying in SQL to retrieve data from the database, aggregation functions group by and having clauses, generate and query views.

Unit 5 (11 hours)

Database Design: Mapping an Entity Relationship diagram to corresponding relational database scheme, functional dependencies and Normal forms, 1NF, 2NF, and 3NF decompositions and desirable properties of them.

Essential/recommended readings

1. Elmasri, R., Navathe, B. S., *Fundamentals of Database Systems*, 7th Edition, Pearson Education, 2016.
2. Murach J., *Murach's MySQL,* 3th Edition, Pearson, 2019.

Additional References

1. Connolly T. M., Begg C. E. *Database Systems: A Practical Approach to Design, Implementation, and Management*, 6th edition, Pearson, 2019.
2. Ramakrishnan R., Gehrke J. *Database Management Systems*, 3rd Edition, McGraw-Hill, 2014.
3. Silberschatz A., Korth H.F., Sudarshan S. *Database System Concepts*, 7th Edition, McGraw Hill, 2019.

Suggested Practical List (if any): (30 hours)

Practical exercises based on a given schema.

Create and use the following student-course database schema for a college to answer the given queries using the standalone SQL editor.

STUDENT	**Roll No**	**Student Name**	**Course ID**	**DOB**
	Char(6)	Varchar(20)	Varchar(10)	Date

COURSE	**CID**	**Course Name**	**Course Type**	**Teacher-in-charge**	**Total Seats**	**Duration**
	Char(6)	Varchar (20)	Char (8)	Varchar (15)	Unsigned int	Unsigned int

ADMISSION	**Roll No**	**CID**	**Date of Admission**
	Char(6)	Char(6)	**Date**

Here, Rollno (ADMISSION) and SID (ADMISSION) are foreign keys. Note that course type may have two values viz. Fulltime and Parttime and a student may enroll in any number of courses

1. Retrieve names of students enrolled in any course.
2. Retrieve names of students enrolled in at least one part time course.
3. Retrieve students' names starting with letter 'A'.
4. Retrieve students' details studying in courses 'computer science' or 'chemistry'.
5. Retrieve students' names whose roll no either starts with 'X' or 'Z' and ends with '9'
6. Find course details with more than N students enrolled where N is to be input by the user.
7. Update student table for modifying a student name.
8. Find course names in which more than five students have enrolled
9. Find the name of youngest student enrolled in course 'BSc(P)CS'
10. Find the name of most popular society (on the basis of enrolled students)
11. Find the name of two popular part time courses (on the basis of enrolled students)
12. Find the student names who are admitted to full time courses only.
13. Find course names in which more than 30 students took admission
14. Find names of all students who took admission to any course and course names in which at least one student has enrolled
15. Find course names such that its teacher-in-charge has a name with 'Gupta' in it and the course is full time.
16. Find the course names in which the number of enrolled students is only 10% of its total seats.
17. Display the vacant seats for each course
18. Increment Total Seats of each course by 10%
19. Add enrollment fees paid ('yes'/'No') field in the enrollment table.
20. Update the date of admission for all the courses by 1 year.
21. Create a view to keep track of course names with the total number of students enrolled in it.

22. Count the number of courses with more than 5 students enrolled for each type of course.
23. Add column Mobile number in student table with default value '9999999999'
24. Find the total number of students whose age is > 18 years.
25. Find names of students who are born in 2001 and are admitted to at least one part time course.
26. Count all courses having 'science' in the name and starting with the word 'BSc'.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

GENERIC ELECTIVES : Java Programming

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course	Department offering the course
		Lecture	Tutorial	Practical/ Practice			
GE: Java Programming	**4**	**3**	**0**	**1**	**Pass in class XII**	NIL	**Computer Science**

Learning Objectives

This course is designed to develop understanding of object-oriented programming concepts like Classes, Objects, Inheritance and Polymorphism using Java. The course provides understanding of multithreading and exception handling in Java. It also introduces how to create Java applications with graphical user interface (GUI).

Learning outcomes

On completion of this course, the student will be able to:

- Understand the object-oriented concepts – Classes, Objects, Inheritance, Polymorphism– for problem solving.
- Create and handle multithreading.
- Handle program exceptions.
- Handle input/output through files.
- Create Java applications with a graphical user interface (GUI).

SYLLABUS OF GE

Unit 1 (6 hours)

Introductory Concepts: program, identifiers, variables, constants, primitive data types, expressions, Naming Conventions, Type casting, operators, control statements, structured data types, arrays, functions.

Unit 2 (13 hours)

Object Oriented Concepts: Abstraction, encapsulation, objects, classes, methods, constructors, inheritance, polymorphism, static and dynamic binding, Anonymous block, Static Data members, overloading and overriding, Usage of super and this keyword, Abstract classes, Interfaces and Packages, Access modifiers, Object class

Unit 3 (11 hours)

Multithreading: Creating Threads, Thread Priority, Blocked States, Extending Thread Class, Runnable Interface, Starting Threads, Thread Synchronization, Sync Code Block, Overriding Synced Methods, Thread Communication, wait, notify and notify all.

Unit 4 (8 hours)

Introduction to Exception handling: Exception and Error, Throw, try and catch Blocks, Exception handlers, java.lang Exceptions, Built-InExceptions.

Unit 5 (7 hours)

Introduction to File Handling: Byte Stream, Character Stream, File I/O Basics, File Operations, Serialization.

Essential/recommended readings

1. Cay S. Horstmann, *Core Java - Vol. I – Fundamentals*, 10th edition, Pearson, 2017.
2. James Gosling, Bill Joy, Guy L. Steele Jr, Gilad Bracha, Alex Buckley, *The Java Language Specification*, *Java SE* 7th edition, Addison-Wesley, 2011

Additional References

1. Herbert Schildt, *Java: The Complete Reference*, 10th edition, McGraw-Hill Education, 2018.

2 Richard Johnson, *An Introduction to Java Programming and Object-Oriented Application Development*, Thomson Learning, 2006.

3. Kathy Sierra and Bert Bates, *Head First Java*, 3rd edition, O'Reilly, 2022.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

1. Create a java program to implement stack and queue concepts.
2. Write a program to take input from command line arguments.
3. Write a java program to show static and dynamic polymorphism.
4. Write a java program to show multiple inheritance using interfaces.
5. Write a program in java to show the chaining of execution of construction.
6. Write a java program to show multithreaded producer and consumer applications.
7. write a program in java to synchronize the multithreaded application
8. Create a customized exception and also make use of all the exception keywords.
9. Write a program to show different ways to get input from user
10. Design a form using AWT components and the Frame container.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

(Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the three Core Disciplines)

DISCIPLINE SPECIFIC CORE COURSE (DSC-3): Computer System Architecture

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC03: Computer System Architecture	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	NIL

Learning Objectives

This course introduces students to the fundamental concepts of digital computer organization, design, and architecture. It aims to develop a basic understanding of the building blocks of a computer system and highlights how these blocks are organized together to architect a digital computer system.

Learning outcomes

On successful completion of the course, students will be able to:

- Design combinatorial circuits using basic building blocks. Simplify these circuits using Boolean algebra and Karnaugh maps. Differentiate between combinational circuits and sequential circuits.
- Represent data in binary form, convert numeric data between different number systems, and perform arithmetic operations in binary.
- Determine various stages of the instruction cycle and describe interrupts and their handling.
- Explain how the CPU communicates with memory and I/O devices.
- Simulate the design of a basic computer using a software tool.

SYLLABUS OF DSC-3

Unit 1 (9 hours)

Digital Logic Circuits: Digital Logic Gates, Flip flops and their characteristic table, Logic circuit simplification using Boolean algebra and Karnaugh map, Don't care conditions, Combinational circuits, Introduction to Sequential Circuits

Unit 2 (7 hours)

Digital Components: Decoders, Encoders, Multiplexers, Binary Adder, Binary Adder Subtractor, Binary Incrementor, Registers, and Memory Units

Unit 3 (13 hours)

Data Representation: Binary representation of both numeric and alphanumeric data, representation of numeric data in different number systems, (Binary, Octal, Decimal and Hexadecimal), conversion from one number system to another, complements, representation of signed and unsigned numbers, addition and subtraction of signed and unsigned numbers and overflow detection.

Unit 4 (9 hours)

Basic Computer Organization and Design: Stored program organization, Computer registers, Instruction set and their completeness, Instruction cycle, Memory reference instructions, Register reference instructions, Input- Output reference instructions, Interrupt cycle, Addressing modes.

Unit 5 (7 hours)

Input-Output Organization: I/O interface, I/O vs. Memory Bus, Isolated I/O, Memory Mapped I/O, Direct Memory Access.

Essential/recommended readings

1. M. Morris Mano, *Computer System Architecture*, 3rd edition, Pearson Education, 2017.
2. Linda Null, Julia Lobur, *Essentials of Computer Organization and Architecture*, 5th Edition, 2019.

Additional References

1. D. Comer, *Essentials of Computer Architecture,* 2nd edition, CRC Press, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

(Use Simulator – CPU Sim 3.6.9 or any higher version for the implementation)

1. Create a machine based on the following architecture:

Registers

IR	DR	AC	AR	PC	I	E
16 bits	16 bits	16 bits	12 bits	12 bits	1 bit	1 bit

Memory 4096 words	

16 bits per word	Instruction format 15 12 11 0 Opcode | Address

Basic Computer Instructions

Memory Reference			Register Reference	
Symbol	Hex		Symbol	Hex
AND	0xxx	Direct Addressing	CLA	7800
ADD	1xxx		CLE	7400
LDA	2xxx		CMA	7200
STA	3xxx		CME	7100
			HLT	7001

Refer to Chapter-5 for a description of the instructions.

Design the register set, the memory, and the instruction set. Use this machine for the assignments in this section.

1. Implement fetch sequence
2. Write an assembly program to simulate the addition of two numbers when one is stored in memory and another is entered by the user.
3. Write an assembly program to simulate addition of two numbers when both numbers are taken as inputs from user.
4. Write an assembly program to simulate subtraction of two numbers when one number is stored in memory and another is entered by the user.

5. Write an assembly program to simulate subtraction of two numbers when both numbers are taken as inputs from user

6. Write an assembly program to simulate the following logical operations on two user-entered numbers.

i.AND

ii.OR

iii.NOT

7. Write an assembly language program to simulate the machine for following register reference instructions and determine the contents of AC, E, PC, AR and IR registers in decimal after the execution:

i. CLE

ii. CLA

iii. CMA

iv. CME

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the two Core Disciplines
(For e.g. courses for B.A. Programmes with Computer Science as Major discipline)

DISCIPLINE SPECIFIC CORE COURSE (DSC-3): Computer System Architecture

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC03: Computer System Architecture	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	NIL

Learning Objectives

This course introduces students to the fundamental concepts of digital computer organization, design, and architecture. It aims to develop a basic understanding of the building blocks of a computer system and highlights how these blocks are organized together to architect a digital computer system.

Learning outcomes

On successful completion of the course, students will be able to:

- Design combinatorial circuits using basic building blocks. Simplify these circuits using Boolean algebra and Karnaugh maps. Differentiate between combinational circuits and sequential circuits.
- Represent data in binary form, convert numeric data between different number systems, and perform arithmetic operations in binary.
- Determine various stages of the instruction cycle and describe interrupts and their handling.
- Explain how the CPU communicates with memory and I/O devices.
- Simulate the design of a basic computer using a software tool.

SYLLABUS OF DSC-3

Unit 1 (9 hours)

Digital Logic Circuits: Digital Logic Gates, Flip flops and their characteristic table, Logic circuit simplification using Boolean algebra and Karnaugh map, Don't care conditions, Combinational circuits, Introduction to Sequential Circuits

Unit 2 (7 hours)

Digital Components: Decoders, Encoders, Multiplexers, Binary Adder, Binary Adder Subtractor, Binary Incrementor, Registers, and Memory Units

Unit 3 (13 hours)

Data Representation: Binary representation of both numeric and alphanumeric data, representation of numeric data in different number systems, (Binary, Octal, Decimal and Hexadecimal), conversion from one number system to another, complements, representation of signed and unsigned numbers, addition and subtraction of signed and unsigned numbers and overflow detection.

Unit 4 (9 hours)

Basic Computer Organization and Design: Stored program organization, Computer registers, Instruction set and their completeness, Instruction cycle, Memory reference instructions, Register reference instructions, Input- Output reference instructions, Interrupt cycle, Addressing modes.

Unit 5 (7 hours)

Input-Output Organization: I/O interface, I/O vs. Memory Bus, Isolated I/O, Memory Mapped I/O, Direct Memory Access.

Essential/recommended readings

1. M. Morris Mano, *Computer System Architecture*, 3rd edition, Pearson Education, 2017.
2. Linda Null, Julia Lobur, *Essentials of Computer Organization and Architecture*, 5th Edition, 2019.

Additional References

2. D. Comer, *Essentials of Computer Architecture,* 2nd edition, CRC Press, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

(Use Simulator – CPU Sim 3.6.9 or any higher version for the implementation)

1. Create a machine based on the following architecture:

Registers

IR	DR	AC	AR	PC	I	E
16 bits	16 bits	16 bits	12 bits	12 bits	1 bit	1 bit

Memory 4096 words	

16 bits per word	Instruction format 15 12 11 0 Opcode | Address

Basic Computer Instructions

Memory Reference			Register Reference	
Symbol	Hex		Symbol	Hex
AND	0xxx	Direct Addressing	CLA	7800
ADD	1xxx		CLE	7400
LDA	2xxx		CMA	7200
STA	3xxx		CME	7100
			HLT	7001

Refer to Chapter-5 for a description of the instructions.

Design the register set, the memory, and the instruction set. Use this machine for the assignments in this section.

1. Implement fetch sequence
2. Write an assembly program to simulate the addition of two numbers when one is stored in memory and another is entered by the user.
3. Write an assembly program to simulate addition of two numbers when both numbers are taken as inputs from user.
4. Write an assembly program to simulate subtraction of two numbers when one number is stored in memory and another is entered by the user.

5. Write an assembly program to simulate subtraction of two numbers when both numbers are taken as inputs from user

6. Write an assembly program to simulate the following logical operations on two user-entered numbers.

i.AND

ii.OR

iii.NOT

7. Write an assembly language program to simulate the machine for following register reference instructions and determine the contents of AC, E, PC, AR and IR registers in decimal after the execution:

i. CLE

ii. CLA

iii. CMA

iv. CME

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE : Data Mining-I

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CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Data Mining - I	4	3	0	1	Passed 12th class with Mathematics	Programming using Python

Learning Objectives

This course aims to introduce data mining techniques and their application on real-life datasets. The students will learn to pre-process the dataset and make it ready for application

of data mining techniques. The course will focus on three main techniques of data mining i.e. Classification, Clustering and Association Rule Mining. Different algorithms for these techniques will be discussed along with appropriate evaluation metrics to judge the performance of the results delivered.

Learning outcomes

On successful completion of the course, students will be able to:

- Pre-process the data for subsequent data mining tasks
- Apply a suitable classification algorithm to train the classifier and evaluate its performance.
- Apply appropriate clustering algorithm to cluster the data and evaluate clustering quality
- Use association rule mining algorithms and generate frequent item-sets and association rules

SYLLABUS

Unit 1 (8 hours)

Introduction to Data Mining: Motivation and Challenges for data mining, Types of data mining tasks, Applications of data mining, Data measurements, Data quality, Supervised vs. unsupervised techniques

Unit 2 (9 hours)

Data Pre-Processing: Data aggregation, sampling, dimensionality reduction, feature subset selection, feature creation, variable transformation.

Unit 3 (11 hours)

Cluster Analysis: Basic concepts of clustering, measure of similarity, types of clusters and clustering methods, K-means algorithm, measures for cluster validation, determine optimal number of clusters

Unit 4 (8 hours)

Association Rule Mining: Transaction data-set, frequent itemset, support measure, rule generation, confidence of association rule, Apriori algorithm, Apriori principle

Unit 5 (9 hours)

Classification: Naive Bayes classifier, Nearest Neighbour classifier, decision tree, overfitting, confusion matrix, evaluation metrics and model evaluation.

Essential/recommended readings

1. Tan P.N., Steinbach M, Karpatne A. and Kumar V. *Introduction to Data Mining,* 2nd edition, Pearson, 2021.
2. Han J., Kamber M. and Pei J. *Data Mining: Concepts and Techniques*, 3rd edition, 2011, Morgan Kaufmann Publishers.
3. Zaki M. J. and Meira J. Jr. *Data Mining and Machine Learning: Fundamental Concepts and Algorithms*, 2nd edition, Cambridge University Press, 2020.

Additional References

1. Aggarwal C. C. *Data Mining: The Textbook*, Springer, 2015.

2. Dunham M. *Data Mining: Introductory and Advanced Topics,* 1st edition, Pearson Education India, 2006.

Recommended Datasets for :

Classification: Abalone, Artificial Characters, Breast Cancer Wisconsin (Diagnostic)

Clustering: Grammatical Facial Expressions, HTRU2, Perfume data

Association Rule Mining: MovieLens, Titanics

Suggested Practicals List (If any): (30 Hours)

Practical exercise such as

1. Apply data cleaning techniques on any dataset (e,g, wine dataset). Techniques may include handling missing values, outliers, inconsistent values. A set of validation rules can be prepared based on the dataset and validations can be performed.
2. Apply data pre-processing techniques such as standardization/normalization, transformation, aggregation, discretization/binarization, sampling etc. on any dataset
3. Run Apriori algorithm to find frequent itemsets and association rules on 2 real datasets and use appropriate evaluation measures to compute correctness of obtained patterns
   a) Use minimum support as 50% and minimum confidence as 75%
   b) Use minimum support as 60% and minimum confidence as 60 %

4. Use Naive bayes, K-nearest, and Decision tree classification algorithms and build classifiers on any two datasets. Divide the data set into training and test set. Compare the accuracy of the different classifiers under the following situations:
   I. a) Training set = 75% Test set = 25% b) Training set = 66.6% (2/3rd of total), Test set = 33.3%
   II. Training set is chosen by i) hold out method ii) Random subsampling iii) Cross-Validation. Compare the accuracy of the classifiers obtained.

   Data is scaled to standard format.
5. Use Simple K-means algorithm for clustering on any dataset. Compare the performance of clusters by changing the parameters involved in the algorithm. Plot MSE computed after each iteration using a line plot for any set of parameters.

Project: Students should be promoted to take up one project on any UCI/kaggle/data.gov.in or a dataset verified by the teacher. Preprocessing steps and at least one data mining technique should be shown on the selected dataset. This will allow the students to have a practical knowledge of how to apply the various skills learnt in the subject for a single problem/project.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the two Core Disciplines
(For e.g. courses for B.A. Programmes with Computer Science as Non-major Discipline)

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC03: Computer System Architecture	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	NIL

Learning Objectives

This course introduces students to the fundamental concepts of digital computer organization, design, and architecture. It aims to develop a basic understanding of the building blocks of a computer system and highlights how these blocks are organized together to architect a digital computer system.

Learning outcomes

On successful completion of the course, students will be able to:

- Design combinatorial circuits using basic building blocks. Simplify these circuits using Boolean algebra and Karnaugh maps. Differentiate between combinational circuits and sequential circuits.
- Represent data in binary form, convert numeric data between different number systems, and perform arithmetic operations in binary.
- Determine various stages of the instruction cycle and describe interrupts and their handling.
- Explain how the CPU communicates with memory and I/O devices.
- Simulate the design of a basic computer using a software tool.

SYLLABUS OF DSC-3

Unit 1 (9 hours)

Digital Logic Circuits: Digital Logic Gates, Flip flops and their characteristic table, Logic circuit simplification using Boolean algebra and Karnaugh map, Don't care conditions, Combinational circuits, Introduction to Sequential Circuits

Unit 2 (7 hours)

Digital Components: Decoders, Encoders, Multiplexers, Binary Adder, Binary Adder Subtractor, Binary Incrementor, Registers, and Memory Units

Unit 3 (13 hours)

Data Representation: Binary representation of both numeric and alphanumeric data, representation of numeric data in different number systems, (Binary, Octal, Decimal and Hexadecimal), conversion from one number system to another, complements, representation of signed and unsigned numbers, addition and subtraction of signed and unsigned numbers and overflow detection.

Unit 4 (9 hours)

Basic Computer Organization and Design: Stored program organization, Computer registers, Instruction set and their completeness, Instruction cycle, Memory reference instructions, Register reference instructions, Input- Output reference instructions, Interrupt cycle, Addressing modes.

Unit 5 (7 hours)

Input-Output Organization: I/O interface, I/O vs. Memory Bus, Isolated I/O, Memory Mapped I/O, Direct Memory Access.

Essential/recommended readings

1. M. Morris Mano, *Computer System Architecture*, 3rd edition, Pearson Education, 2017.
2. Linda Null, Julia Lobur, *Essentials of Computer Organization and Architecture*, 5th Edition, 2019.

Additional References

3. D. Comer, *Essentials of Computer Architecture,* 2nd edition, CRC Press, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

(Use Simulator – CPU Sim 3.6.9 or any higher version for the implementation)

1. Create a machine based on the following architecture:

Registers

IR	DR	AC	AR	PC	I	E
16 bits	16 bits	16 bits	12 bits	12 bits	1 bit	1 bit

Memory 4096 words 16 bits per word	Instruction format 15 12 11 0

	Opcode	Address

Basic Computer Instructions

Memory Reference			Register Reference	
Symbol	Hex		Symbol	Hex
AND	0xxx	Direct Addressing	CLA	7800
ADD	1xxx		CLE	7400
LDA	2xxx		CMA	7200
STA	3xxx		CME	7100
			HLT	7001

Refer to Chapter-5 for a description of the instructions.

Design the register set, the memory, and the instruction set. Use this machine for the assignments in this section.

1. Implement fetch sequence
2. Write an assembly program to simulate the addition of two numbers when one is stored in memory and another is entered by the user.
3. Write an assembly program to simulate addition of two numbers when both numbers are taken as inputs from user.
4. Write an assembly program to simulate subtraction of two numbers when one number is stored in memory and another is entered by the user.
5. Write an assembly program to simulate subtraction of two numbers when both numbers are taken as inputs from user
6. Write an assembly program to simulate the following logical operations on two user-entered numbers.

i.AND

ii.OR

iii.NOT

7. Write an assembly language program to simulate the machine for following register reference instructions and determine the contents of AC, E, PC, AR and IR registers in decimal after the execution:

i. CLE

ii. CLA

iii. CMA

iv. CME

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DEPARTMENT OF OPERATIONAL RESEARCH

B.SC. (HONS) OPERATIONAL RESEARCH

Category I

DISCIPLINE SPECIFIC CORE COURSE – 7: CONVEX AND DISCRETE OPTIMIZATION

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Convex and Discrete Optimization (DSC-7)	4	3	1	0	Passed 12th class with Mathematics	Linear Programming

Learning Objectives:

- To impart knowledge about the formulations and solution techniques of integer linear and multi-objective goal programming problems.

Learning Outcomes:

On successful completion of the course, students will be able to:

- Identify different types of optimization problems which occur in real life and their characteristics.
- Explain the theoretical concepts related to unconstrained optimization problems and demonstrate optimality conditions and solution approaches for them.
- Develop the concepts of a multi-objective programming problem and demonstrate its solution using goal programming.
- Formulate real-life problems as integer linear programming problems and solve them using Branch and Bound method.

SYLLABUS OF DSC-7

Unit I: Unconstrained Optimization **(8 Hours)**

Single and multiple variable problems, Necessary and sufficient conditions for finding extrema, Solution methods: Bisection, Newton, Golden section, Gradient search.

Unit II: **Convex Functions** **(12 Hours)**

Local and global maxima/minima for functions of one and two variables, inflection point, positive/negative definite and semi-definite matrices, convex/concave functions, and their properties, Verifying convexity/concavity through a Hessian matrix.

Unit III: Goal Programming **(12 Hours)**

Goal Programming: Basics of goal programming, Weighted and pre-emptive goal programming, Formulation of a goal programming problem, Graphical solution method, Modified Simplex method.

Unit IV: Integer Linear Programming **(13 Hours)**

Introduction to Integer linear programming problem (ILPP), Pure ILPP, Mixed ILPP, and 0-1 ILPP, Applications of ILPP: Capital budgeting, problem Fixed charge problem, Travelling salesman problem, Media allocation, Knapsack problem, Gomory's cutting plane method, Branch and bound method.

References:

1. Chandra, S., Jayadeva, & Mehra, A. (2013). *Numerical optimization with applications.* New Delhi: Narosa Publishing House.
2. Ravindran, A., Phillips, D. T., & Solberg, J. J. (2007). *Operations research- principles and practice* (2nd ed.). New Delhi: Wiley India (Indian print).
3. Sinha, S. M. (2006). *Mathematical programming- theory and methods* (1st ed.). New Delhi: Elsevier Science (Indian print).

Practical component (if any) – NIL

Essential Readings:

- Bazaraa, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear programming-Theory and algorithms (3rd ed.).* New Delhi: John Wiley & Sons (Indian print).
- Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical optimization with applications*. New Delhi: Narosa Publishing House.

Suggested Readings:

- Antoniou, A., & Lu, Wu-Sheng (2007). *Practical optimization- Algorithms and engineering applications*. New York: Springer.
- Hillier, F. S., & Lieberman, G. J. (2010). *Introduction to operations research- Concepts and cases (9th ed.).* New Delhi: Tata McGraw Hill (Indian print).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 8: ADVANCED CALCULUS

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Advanced Calculus (DSC-8)	4	3	1	0	Passed 12th class with Mathematics	Calculus

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint the students with the advanced concepts in Calculus
- To make the students learn effective methods of calculus
- To make the student understand the quantitative change in the behaviour of the variables and apply them on the problems related to Operational Research domain

Learning Outcomes

On successful completion of the course, students will be able to:

- Understand the concepts of function of one variable to functions of two or more variables.
- Evaluate double integral based problems
- Analyse integration based problems in real life cases.
- Understand Calculus.

SYLLABUS OF DSC-8

Unit I: Differential calculus **(15 Hours)**

Function of Two Variables, Limits and continuity, Partial differentiation, Total differential, Approximation, Higher order partial derivative, Homogeneous Function, Taylor's Theorem for

two variables, Maxima and Minima for functions of Two Variables, Lagrange Multiplier and Constrained optimization.

Unit II: Integral calculus **(10 Hours)**
Double Integral, Double Integration over rectangular and nonrectangular regions, Change of variables in integrals.

Unit III: Differential equations **(20 Hours)**
Order and degree of a differential equation, Exact differential equations, Differential equations of first order and first degree, Higher Order Differential Equations: Homogeneous linear differential equations of order n with constant coefficients, The Cauchy-Euler's equation of order n, Method of variation of parameters, Application of differential equations to operational research problems.

Practical component (if any) – Nil

Essential/recommended readings

- Strauss, M. J., Bradley, G. L., & Smith, K. J. (2007). *Calculus* (3rd Edition). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi. Sixth impression 2011.
- Ross, Shepley. L. (1984). Differential equations (3rd ed.). John Wiley & Sons.
- Kreyszig, E. (2007). *Advanced Engineering Mathematics* (9th Edition). Wiley Plus Set (p. 334). John Wiley & Sons.
- Marsden, J., & Weinstein, A. (1985). *Calculus I*. Springer Science & Business Media.
- Yamada, S. (2014). *Software Reliability Modeling: Fundamentals and Applications*. Tokyo: Springer.

Suggestive readings

- Shanti Narayan and P K Mittal (2018). *Differential Calculus. 15th Ed (Revised).*, S Chand Publication, New Delhi
- Shanti Narayan and P K Mittal (2016). *Integral Calculus. 11th Ed (Revised*), S Chand Publication, New Delhi.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 9: QUEUING THEORY

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Queuing Theory (DSC-9)	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce queuing (waiting lines) models and their applications in real-life situations.
- To provide necessary mathematical support and confidence to the students to tackle real life problems.
- To make students learn both theory and applications of fundamental and advanced models in this field.

Learning outcomes

On successful completion of the course, students will be able to:

- Understand the concepts of stochastic processes, Markov processes, Markov chains and apply these in analysing queuing systems.
- Understand the concepts and analyse the mathematical theory related to queuing systems.
- Analyse and compute quantitative measures of performance for queuing systems.
- Apply and extend queuing models to analyse real world systems.

SYLLABUS OF DSC-9

Unit I: Queueing systems **(6 Hours)**

Basic characteristics, measures of performance and Kendall's notation. Little's formula, traffic intensity.

Unit II: Stochastic processes **(10 Hours)**

Definition and classification on the basis of state and parameter space. Markov chain: definition, transition probability matrix (TPM), classification of states. Continuous-time

Markov chains: Poisson process (definition and its relationship with exponential distribution), pure birth process and pure death process.

Unit III: Markovian queueing models **(20 Hours)**

General birth-death processes, single-server queue (M/M/1), multi-server queue (M/M/c), queue with finite capacity (M/M/c/K), Erlang's loss formula (M/M/c/c), queues with unlimited service (M/M/∞), finite-source queues, queues with impatience (M/M/1 with balking and M/M/1 with reneging).

Unit IV: Decision problems in queueing theory **(9 Hours)**

Descriptive and prescriptive modeling, performance measures of decision-making, queueing design problems, queueing control problems.

Practical component (if any) – **(30 Hours)**

- Finding measures of performance for deterministic queuing system.
- Finding measures of performance for M/M/1 queuing system with infinite capacity.
- Finding measures of performance for M/M/1 queuing system with finite capacity.
- Finding measures of performance for M/M/c queuing system with infinite capacity.
- Finding measures of performance for M/M/c queuing system with finite capacity.
- Finding measures of performance for any Markovian queuing system with multiple servers and with finite/infinite capacity.

Essential/recommended readings

- Cooper, R. B. (1981). *Introduction to Queueing Theory* (2nd Edition). North Holland.
- Kleinrock L. (1975). *Queueing Systems*, Volume 1: Theory, John Wiley.
- Gross, Donald, Shortle , John F., Thompson, James M., and Harris, Carl M. (2008). *Fundamentals of Queueing Theory* (5th Edition), John Wiley and Sons Inc. Pte. Ltd.
- Bhat, U. N. (2008). *An introduction to Queueing Theory: Modelling and Analysis in Applications (Statistics for Industry and Technology)*. Birkhauser Boston.
- Cox, D. R. and Smith ,W. L. (1991). *Queues*. Chapman and Hall/CRC.
- Medhi, J. (2002). *Stochastic Models in Queueing Theory* (2nd Edition), Academic Press.
- Satty, T. L. (1983). *Elements of Queueing Theory with Applications*, Dover Publications, NY.
- Prabhu, N. U. (2012). *Foundations of Queueing Theory (International Series in Operations Research & Management Science)*, Springer.

Suggestive readings-Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category II

(B.A. Programme with Operational Research as Major discipline)

DISCIPLINE SPECIFIC CORE COURSE – 5: Mathematical Modelling for Business

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-5)	4	3	0	1	Passed 12th class with Mathematics	Linear Programming

Learning Objectives

To acquaint students with different mathematical modelling techniques applicable in various businesses viz., inventory control, marketing management, and network flow analysis.

Learning outcomes

On successful completion of the course, students will be able to:

- Explain the meaning of Inventory control, its various forms, and the functional role of Inventory.
- Calculate the Economic Order Quantity (EOQ) for various Deterministic Inventory models.
- Comprehend inventory models with All Units Quantity Discounts
- Gain an understanding of the basic concepts and issues in marketing and their application in business decisions.
- Gain an understanding of network analysis and related mathematical models.
- Use standard methodologies for solving network flow problems.

SYLLABUS OF DSC-5

Unit I: Introduction to Inventory Management **(18 Hours)**

Concept and significance of inventory management, Different types of costs in the inventory system. Deterministic continuous review models: Economic order quantity (EOQ) model with and without shortages, Finite replenishment rate Inventory models without and with planned shortages. Determination of reorder point for all the models. Inventory models with All Units Quantity Discounts.

Unit II: Fundamentals for Marketing Management **(15 Hours)**

Nature, Scope, and Importance of Marketing, Basic concepts, Marketing Environment, Consumer Behaviour, Market Classification based on Competitive Conditions, Product Mix, Pricing Strategies, Media allocation for advertisement, Brand switching analysis, Concept of Measurement of Elasticity of Demand, Factors Affecting Elasticity of Demand, Income Elasticity of Demand, Cross Elasticity of Demand, Advertising Elasticity of Demand.

Unit III: Network Analysis **(12 Hours)**

Understanding of network components, Construction of network diagram, Introduction to Network flow problems and their applications: Shortest path problem, Travelling salesman problem, minimum spanning tree.

Practical component (if any) - **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages

- To find optimal inventory policy for deterministic inventory models without shortages.
- To find optimal inventory policy for deterministic inventory models without shortages.
- To solve all units quantity discounts model.
- Finding shortest path in a network.
- Solving a travelling salesman problem.
- Finding minimum spanning tree in a network.
- Problems based on media allocation for advertisement.
- Problems based on Brand switching analysis.

Essential/recommended readings

- Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2011). Linear programming and network flows. John Wiley & Sons.
- Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
- Waters, D. (2008). *Inventory control and management.* (2nd Edition). John Wiley & Sons.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.

Suggestive readings Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 6: Python Programming

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Python Programming (DSC-6)	4	3	0	1	Passed 12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce the basic concepts of Python programming. The course will familiarize the students with Python's ability to handle different data formats such as numbers, strings, lists, dictionaries, sets, tuples, etc.
- The students will be made familiar with the concepts of loops. Modularization of code using inbuilt functions as well as user defined functions will also be explained.
- To introduce the basics for various useful libraries so as to equip the students with modern computing skills.

Learning outcomes

On successful completion of the course, students will be able to:

- Learn Python installation and configuration.
- Understand simple scripting using Python.
- Learn Syntax and Semantics of Python Programming.
- Understand different data types and arithmetical, logical and relational expressions in Python.
- Understand the control structures and functions in Python by writing codes for some real-world problems.
- Handle simple data structures, lists, dictionaries, sets and tuples.
- Modularize the code using inbuilt functions and user defined functions.
- Handle various managerial decision making related problems

SYLLABUS OF DSC-6

Unit I: Introduction **(6 Hours)**

Python installation, Basic Terminal Commands, interactive mode and script mode, Structure of a Program, Simple Python Script Writing, script execution, debugging errors and understanding simple programs in Python

Unit II: Understanding Control Statements **(6 Hours)**
Identifiers and keywords; literals, numbers, and strings; Operators and expressions; Input and Output statements; control structures (conditional statements, loop control statements, break, Continue and pass).

Unit III: Functions **(10 Hours)**
Introduction to Functions and its definition: Modules, built in and user-defined functions, passing arguments and returning values, default arguments, functions as data.

Unit IV: Data Structures **(10 Hours)**
Data Structures like; Strings, Lists, Tuples, Sets, Dictionaries, Analysing their functions and basic operations.

Unit V: Advance Libraries **(13 Hours)**
Introduction to Core Libraries in Python : Numpy Library for Arrays (Creating and accessing One and Multi-Dimensional Array), Pandas Library for Data Processing (Basics of DataFrame), Matplotlib Library for Visualization (Pie Chart, Scatter Plot, Histogram, Bar Chart)

Practical component (if any) – **(30 Hours)**

- Write a program to enter a name and display: "Hello, Name".
- Write a program to compute the roots of a quadratic equation.
- Write a program to print a pyramid **pattern** with 8 rows.
- Write a menu driven program to enter a number and print whether the number is odd or even.
- Write a program to build a **random number generator** that generates random numbers between 1 and 6 (simulates a dice).
- Write a program that takes two **lists** and returns "True" if they have at least one common member.
- Write a program to check if one **list** is reverse of another.
- Write a program to check if a given **array** is Monotonic.
- Write a program to find the maximum number out of 3 entered numbers. **(loop)**
- Write a program to build a menu driven **calculator** and perform basic arithmetic operations between two numbers. (Addition, Subtraction, Multiplication and Division)
- Write a program to create a **dictionary** and remove one key.
- Write a program to enter 5 subject's marks and print the grades A/B/C/D. **(loop)**
- Write a program to print a Fibonacci sequence. **(loop)**
- Write a program in python to plot a **graph** for the function $y = x^2$.
- Programmes related to creating and modifying List, Tuple and Dictionary.
- Programmes to find correlation between dependent and independent variables.
- Programme to develop a regression model on an existing data set.
- Programmes for data visualization (Charts using plot() function, Pie Chart, Scatter Plot, Histogram, Bar Chart)
- Solution to deterministic EOQ based models for Inventory Management

Essential/recommended readings

- Deitel, P. J. (2019). P*ython Fundamentals*. Pearson.

- Dierbach, C. (2012). *Introduction to computer science using python: a computational problem-solving focus.* Wiley Publishing.
- Guttag, J. V. (2013). *Introduction to computation and programming using Python*. MIT Press.
- Lambert, K. A. (2018*). Fundamentals of python: first programs*. Cengage Learning.
- Lutz, M., & Lutz, M. (1996). *Programming python* (volume 8). O'Reilly Media, Inc.
- Thareja, R. (2017). *Python programming using problem solving approach*. Oxford University Press.
- VanderPlas, J. (2016). *Python data science handbook: essential tools for working with data.* O'Reilly Media, Inc.

Suggestive readings:: NIL

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category III

(B.A Programme with Operational Research as non-Major or Minor discipline)

DISCIPLINE SPECIFIC CORE COURSE – 3: Mathematical Modelling for Business

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-3)	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	**Linear Programming**

Learning Objectives

To acquaint students with different mathematical modelling techniques applicable in various businesses viz., inventory control, marketing management, and network flow analysis.

Learning outcomes

On successful completion of the course, students will be able to:

- Explain the meaning of Inventory control, its various forms, and the functional role of Inventory.
- Calculate the Economic Order Quantity (EOQ) for various Deterministic Inventory models.
- Comprehend inventory models with All Units Quantity Discounts
- Gain an understanding of the basic concepts and issues in marketing and their application in business decisions.
- Gain an understanding of network analysis and related mathematical models.
- Use standard methodologies for solving network flow problems.

SYLLABUS OF DSC-5

Unit I: Introduction to Inventory Management **(18 Hours)**

Concept and significance of inventory management, Different types of costs in the inventory system. Deterministic continuous review models: Economic order quantity (EOQ) model with and without shortages, Finite replenishment rate Inventory models without and with planned shortages. Determination of reorder point for all the models. Inventory models with All Units Quantity Discounts.

Unit II: Fundamentals for Marketing Management **(15 Hours)**

Nature, Scope, and Importance of Marketing, Basic concepts, Marketing Environment, Consumer Behaviour, Market Classification based on Competitive Conditions, Product Mix, Pricing Strategies, Media allocation for advertisement, Brand switching analysis, Concept of Measurement of Elasticity of Demand, Factors Affecting Elasticity of Demand, Income Elasticity of Demand, Cross Elasticity of Demand, Advertising Elasticity of Demand.

Unit III: Network Analysis **(12 Hours)**

Understanding of network components, Construction of network diagram, Introduction to Network flow problems and their applications: Shortest path problem, Travelling salesman problem, minimum spanning tree.

Practical component (if any) - **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages

- To find optimal inventory policy for deterministic inventory models without shortages.
- To find optimal inventory policy for deterministic inventory models without shortages.
- To solve all units quantity discounts model.
- Finding shortest path in a network.
- Solving a travelling salesman problem.
- Finding minimum spanning tree in a network.
- Problems based on media allocation for advertisement.
- Problems based on Brand switching analysis.

Essential/recommended readings

- Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2011). Linear programming and network flows. John Wiley & Sons.
- Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
- Waters, D. (2008). *Inventory control and management.* (2nd Edition). John Wiley & Sons.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category IV

BSc. Physical Sciences/ Mathematical Sciences with Operational Research as one of the three Core Disciplines
CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

DISCIPLINE SPECIFIC CORE COURSE – 3: MATHEMATICAL MODELLING FOR BUSINESS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-3)	4	3	0	1	Passed 12th class with Mathematics	Linear Programming

Learning Objectives

To acquaint students with different mathematical modelling techniques applicable in various businesses viz., inventory control, marketing management, and network flow analysis.

Learning outcomes

On successful completion of the course, students will be able to:

- Explain the meaning of Inventory control, its various forms, and the functional role of Inventory.
- Calculate the Economic Order Quantity (EOQ) for various Deterministic Inventory models.
- Comprehend inventory models with All Units Quantity Discounts
- Gain an understanding of the basic concepts and issues in marketing and their application in business decisions.
- Gain an understanding of network analysis and related mathematical models.
- Use standard methodologies for solving network flow problems.

SYLLABUS OF DSC-5

Unit I: Introduction to Inventory Management **(18 Hours)**

Concept and significance of inventory management, Different types of costs in the inventory system. Deterministic continuous review models: Economic order quantity (EOQ) model with

and without shortages, Finite replenishment rate Inventory models without and with planned shortages. Determination of reorder point for all the models. Inventory models with All Units Quantity Discounts.

Unit II: Fundamentals for Marketing Management (15 Hours)

Nature, Scope, and Importance of Marketing, Basic concepts, Marketing Environment, Consumer Behaviour, Market Classification based on Competitive Conditions, Product Mix, Pricing Strategies, Media allocation for advertisement, Brand switching analysis, Concept of Measurement of Elasticity of Demand, Factors Affecting Elasticity of Demand, Income Elasticity of Demand, Cross Elasticity of Demand, Advertising Elasticity of Demand.

Unit III: Network Analysis (12 Hours)

Understanding of network components, Construction of network diagram, Introduction to Network flow problems and their applications: Shortest path problem, Travelling salesman problem, minimum spanning tree.

Practical component (if any) - (30 Hours)

Practical/Lab to be performed on a computer using OR/Statistical packages

- To find optimal inventory policy for deterministic inventory models without shortages.
- To find optimal inventory policy for deterministic inventory models without shortages.
- To solve all units quantity discounts model.
- Finding shortest path in a network.
- Solving a travelling salesman problem.
- Finding minimum spanning tree in a network.
- Problems based on media allocation for advertisement.
- Problems based on Brand switching analysis.

Essential/recommended readings

- Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2011). Linear programming and network flows. John Wiley & Sons.
- Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
- Waters, D. (2008). *Inventory control and management.* (2nd Edition). John Wiley & Sons.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CATEGORY-V (a)

COMMON POOL OF DISCIPLINE SPECIFIC ELECTIVES (DSE) COURSES
BSc. Physical Sciences/ Mathematical Sciences with Operational Research as one of the three Core Disciplines

DISCIPLINE SPECIFIC ELECTIVE (DSE): SIMULATION MODELLING & APPLICATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Simulation Modelling and Applications (DSE-1(a))	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the fundamentals of Simulation modelling
- Develop the students' analytical skills
- Introduce simulation techniques applicable in different situations

Learning outcomes

On successful completion of the course, students will be able to:

- Know the basics of simulation modelling and its scope.
- Gain knowledge of Event Type Simulation and its applications in real life.
- Understand the various methods of random number generation.
- Understand and use Monte Carlo Simulation.
- Apply Simulation Technique in Inventory Control, Queuing Systems.
- Use Simulation in Finance and Investment, Maintenance Problems and Networks.

SYLLABUS OF DSE-1(a)

Unit I: Introduction to Simulation **(18 Hours)**

What is Simulation, Process of Simulation, Advantages and Limitations of Simulation, Classification of Simulation Models, Continuous Event Type Simulation, Discrete Event Simulation: Components and Organization, Application of discrete event simulation in single server queueing system, inventory model and insurance risk model.

Unit II : Random Number Generation **(12 Hours)**

Pseudo Random Number Generators – Mixed Congruence Method, Multiplicative Congruential Method, Additive Congruential Method, the inverse transform method, Discrete and Continuous Distributions, Box Muller Method.

Unit III: Applications in Inventory and Queuing **(9 Hours)**

Monte Carlo Simulation, Application of Simulation in Inventory Control, Simulation of Queueing Systems.

Unit IV: Applications in Project Management **(6 Hours)**

Simulation of Maintenance Problems, Applications of Simulation in Finance and Investment, Simulation of Job Sequencing, Simulation of Networks.

Practical component (if any) – **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages

- Modelling randomness in Excel: Pseudo Random Number generators
- Generation of U (0,1)
- Simulating M/M/1 Queues
- Monte Carlo Simulation
- Simulation in Inventory Control
- Forecasting using Simulation
- Simulation in Queueing System using Monte Carlo Simulation
- Simulation in Finance and Investment

Essential/recommended readings

- Fishman, G.S. (1996). *Monte Carlo-Concepts, Algorithms and Applications*, Springer
- Taha, H.A. (2018), *Operations Research, An Introduction, 10h Edition*, Pearson.
- Sheldon M. Ross (2008), *Simulation, 4thEd*, Elsevier.
- Averill M. Law and W. David Kelton (2003), *Simulation Modeling and Analysis*, 3rd Ed., Tata McGraw-Hill.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE): PRODUCTION AND OPERATIONS MANAGEMENT

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Production and Operations Management (DSE-1(b))	4	3	1	0	Passed 12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To make students understand the strategic significance of Production and Operations Management in service and manufacturing organizations.
- To acquaint them with fundamental concepts, functions and applications of discipline, so as to deal with different types of problems faced by operations managers, and common decision-making approaches.

Learning Outcomes

On successful completion of the course, students will be able to:

- Gain an understanding of basic concepts of Production and Operations management and differentiate between them.
- Analyse the factors affecting Facility Capacity, Location, and Layout.
- Understand the Production planning and Material Requirement Planning techniques.
- Comprehend basic concepts in Just in time (JIT) Manufacturing System, Operations scheduling and Quality management.

SYLLABUS

Unit I: Introduction to Production and Operations Management (POM) (6 Hours)
Overview of Production System, Objectives of Operations Management, Scope of Operations Management, Types of Production Systems, Production Design Process and Process choices. Framework for Managing Operations; Strategic Operations Management.

Unit II: Facility Location, Layout and Capacity (12 Hours)
Factors Influencing Plant Location, Single Facility Location Problem, Multi Facility Location Problem, Models for Facility Location Problem. Facility Layout decision- importance and benefits of layout planning, different types of layouts. Capacity Planning – Measures of capacity, factors affecting demand forecasting and capacity planning, short and long-term capacity planning.

Unit III: Production Planning (12 Hours)
Aggregate planning, Master Production Schedule. Introduction to MRP and MRP II. Lot sizing in MRP systems – Lot for lot method, economic quantity method, periodic order quantity method, part period balancing, Wagner – Whitin approach. Introduction to modern productivity techniques – Just in Time (JIT), Kanban system. Inventory Control – basic concepts, Classification of Inventory System, EOQ Model.

Unit IV: Operations Scheduling and Quality Management (15 Hours)
Flow Shop Scheduling- Introduction, Single Machine Scheduling, n jobs m machines, Johnsons' rule. Quality Management: Introduction, Statistical process control, control charts, Total Quality Management (TQM), Six sigma, ISO 9000 and other ISO series.

Practical component (if any) –Nil

Essential/recommended readings

- Bedi, K. (2013). *Production & Operations Management.* 3rd edition. Oxford University Press.
- Everett E. Adam, Ronald J Ebert (1995). *Production and Operations Management: Concepts, Models, and Behavior*. Fifth edition. PHI Learning Pvt. Ltd
- Gaither, N., & Frazier, G. (2002). *Operations management*. South-Western/Thomson Learning.
- Heizer,J., Render, B., Munson, C., & Sachan, A. (2017). *Operations Management*. Twelfth edition. Pearson Education.

Suggestive readings:

Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE : BUSINESS FORECASTING

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Business Forecasting	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The objective of this course is to introduce both managerial and technical aspects of business forecasting to students and expose them to its practical applications.
The Learning Objectives of this course are as follows:

- To introduce both managerial aspect of business forecasting
- Develop the students' ability to understand the technical aspect for business forecasting and its applications
- Introduce various forecasting techniques helpful for better decision making

Learning outcomes

On successful completion of the course, students will be able to:

- Gain an understanding of key concepts of Business Forecasting and its applications.
- Develop analytical methodologies that make prediction of future events of interest to business and industry.
- Make well-informed decisions that require forecasting of relevant variables.
- Identify relevant information to support model selection in scenarios where issues of time series analysis are involved.
- Predict relationships among business and economic variables for supporting short-term and long-term planning.

SYLLABUS OF DSE-1(c)

Unit I: Introduction **(12 Hours)**

Introduction to Business Forecasting, Importance of forecasting, Different types of forecasting methods, Identification of appropriate technique for forecasting, Applications of forecasting methods in industry, Practical issues in forecasting.

Unit II: Time Series Modeling **(15 Hours)**

Time series and its components, modelling and forecasting trend, modelling and forecasting seasonality, characterising cycles in times series, forecasting cycles, Forecasting models with trend seasonality and cycle.

Unit III: Regression Modeling **(9 Hours)**

Simple linear regression and multiple linear regression models and their applications in business.

Unit IV: Some Related Concepts **(9 Hours)**

Stationary and non-stationary time series, Autoregressive (AR) Forecasting model, Moving average (MA) model, Autoregressive moving average model (ARMA), Autoregressive integrated moving average (ARIMA) model, Random walk model. Applications of these models in business.

Practical component (if any) – **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages

- Plot and visualize time series data.
- Fitting of trend by using Method of semi averages.
- Fitting of trend by Moving Average Method.
- Measurement of Seasonal indices using method of simple average.
- Measurement of Seasonal indices using Ratio-to-Trend method.
- Measurement of Seasonal indices using Ratio-to-Moving Average method.
- Measurement of seasonal indices using Link Relative method.
- To find cyclical variations using percentage of trend method and relative cyclical residual method.
- Fitting a simple linear regression model for forecasting.
- Fitting a multiple linear regression model for forecasting.

Essential/recommended readings

- Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (2008). *Forecasting methods and applications*. John wiley & sons.
- Pindyck, R. S., & Rubinfeld, D. L. (1976). *Econometric models and economic forecasts*. McGraw-Hill.
- Butler, W. F., Kavesh, R. A., & Platt, R. B. (Eds.). (1974). *Methods and techniques of business forecasting*. Prentice Hall.
- Diebold, F. X. (2004). *Elements of Forecasting*. Thompson: South Western. Ohio, USA.

Suggestive readings

- Hanke, J. E., & Wichern, D.W. (2014). *Business Forecasting.* Pearson.
- Gujarati, D. N. (2004). *Basic econometrics. (4th ed.),* McGraw-Hill.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CATEGORY-V (b)

COMMON POOL OF DISCIPLINE SPECIFIC ELECTIVES (DSE) COURSES
BSc(Hons.) Operational Research

DISCIPLINE SPECIFIC ELECTIVE (DSE): SIMULATION MODELLING & APPLICATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Simulation Modelling and Applications (DSE-1(a))	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the fundamentals of Simulation modelling
- Develop the students' analytical skills
- Introduce simulation techniques applicable in different situations

Learning outcomes

On successful completion of the course, students will be able to:

- Know the basics of simulation modelling and its scope.
- Gain knowledge of Event Type Simulation and its applications in real life.
- Understand the various methods of random number generation.
- Understand and use Monte Carlo Simulation.
- Apply Simulation Technique in Inventory Control, Queuing Systems.
- Use Simulation in Finance and Investment, Maintenance Problems and Networks.

SYLLABUS

Unit I: Introduction to Simulation **(18 Hours)**
What is Simulation, Process of Simulation, Advantages and Limitations of Simulation, Classification of Simulation Models, Continuous Event Type Simulation, Discrete Event Simulation: Components and Organization, Application of discrete event simulation in single server queueing system, inventory model and insurance risk model.

Unit II : Random Number Generation **(12 Hours)**
Pseudo Random Number Generators – Mixed Congruence Method, Multiplicative Congruential Method, Additive Congruential Method, the inverse transform method, Discrete and Continuous Distributions, Box Muller Method.

Unit III: Applications in Inventory and Queuing **(9 Hours)**
Monte Carlo Simulation, Application of Simulation in Inventory Control, Simulation of Queueing Systems.

Unit IV: Applications in Project Management **(6 Hours)**
Simulation of Maintenance Problems, Applications of Simulation in Finance and Investment, Simulation of Job Sequencing, Simulation of Networks.

Practical component (if any) – **(30 Hours)**
Practical/Lab to be performed on a computer using OR/Statistical packages

- Modelling randomness in Excel: Pseudo Random Number generators
- Generation of U (0,1)
- Simulating M/M/1 Queues
- Monte Carlo Simulation
- Simulation in Inventory Control
- Forecasting using Simulation
- Simulation in Queueing System using Monte Carlo Simulation
- Simulation in Finance and Investment

Essential/recommended readings

- Fishman, G.S. (1996). *Monte Carlo-Concepts, Algorithms and Applications*, Springer
- Taha, H.A. (2018), *Operations Research, An Introduction, 10h Edition*, Pearson.
- Sheldon M. Ross (2008), *Simulation, 4thEd*, Elsevier.
- Averill M. Law and W. David Kelton (2003), *Simulation Modeling and Analysis*, 3rd Ed., Tata McGraw-Hill.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE):

Numerical Analysis

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Numerical Analysis (DSE-1(b))	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the techniques that uses algorithms for approximation problems.
- Develop the students' ability to use various numerical method techniques
- To make the students formulate and apply appropriate strategy to solve real world problems.

Learning outcomes

On successful completion of the course, students will be able to:

- Know the basic elements of numerical methods and error analysis
- Learn Iterative methods for finding the roots of the algebraic and transcendental equations
- Apply the numerical methods to solve system of linear equations and understand the methods convergence analysis.
- Understand the concepts of finite differences, derive the interpolation formulae and understand its applications.

SYLLABUS OF DSE-1(b)

Unit I **(12 Hours)**

Errors: Relative Error, Absolute Error, Round off Error, Truncation Error. Transcendental and Polynomial equations: Bisection method, Newton-Raphson method, Secant method. Method of False Position, Fixed point iterative method, Order and rate of convergence of these methods.

Unit II **(9 Hours)**

System of linear equations: Gauss Elimination and Gauss Jordan methods. Gauss Jacobi method, Gauss Seidel method and their convergence analysis.

Unit III **(9 Hours)**

Interpolation: Lagrange Interpolating Polynomial, Newton's Gregory forward and backward difference interpolating polynomial, Newton's Divided Difference Interpolating Polynomial, Error analysis in each method.

Unit IV **(15 Hours)**

Numerical Integration: Trapezoidal rule, Composite Trapezoidal rule, Simpson's rule, Composite Simpson's rule, Simpsons 3/8th rule. Ordinary Differential Equations: Euler's method, Modified Euler's method, Runge-Kutta method

Practical component (if any) – **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages for developing the following numerical programs:

1. Bisection method
2. Newton Raphson method
3. Secant method
4. Regula Falsi method
5. LU decomposition method
6. Gauss-Jacobi method
7. Gauss-Seidel method
8. Lagrange interpolation
9. Newton interpolation
10. Trapezoidal rule
11. Simpson's rule
12. Euler's method

Essential/recommended readings

- Sastry, S. S. (2012). *Introductory methods of numerical analysis*. PHI Learning Pvt. Ltd..
- Gerald, C. F., & Wheatley, P. O. (2008). *Applied Numerical Analysis (7th ed.).* Pearson Education. India.
- Bradie, Brian. (2006). *A Friendly Introduction to Numerical Analysis*. Pearson Education, India. Dorling Kindersley (India) Pvt. Ltd. Third impression 2011.
- Mudge, M. R. (2003). *An introduction to numerical methods and analysis*,(Wiley).

Suggestive readings:

- Jain, M. K., Iyengar, S. R. K., & Jain, R. K. (2012). *Numerical Methods for Scientific and Engineering Computation. (6th ed.).* New Age International Publisher, India, 2016.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE): BUSINESS FORECASTING

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Business Forecasting	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The objective of this course is to introduce both managerial and technical aspects of business forecasting to students and expose them to its practical applications.
The Learning Objectives of this course are as follows:

- To introduce both managerial aspect of business forecasting
- Develop the students' ability to understand the technical aspect for business forecasting and its applications
- Introduce various forecasting techniques helpful for better decision making

Learning outcomes

On successful completion of the course, students will be able to:

- Gain an understanding of key concepts of Business Forecasting and its applications.
- Develop analytical methodologies that make prediction of future events of interest to business and industry.
- Make well-informed decisions that require forecasting of relevant variables.
- Identify relevant information to support model selection in scenarios where issues of time series analysis are involved.
- Predict relationships among business and economic variables for supporting short-term and long-term planning.

SYLLABUS OF DSE-1(c)

Unit I: Introduction **(12 Hours)**

Introduction to Business Forecasting, Importance of forecasting, Different types of forecasting methods, Identification of appropriate technique for forecasting, Applications of forecasting methods in industry, Practical issues in forecasting.

Unit II: Time Series Modeling **(15 Hours)**

Time series and its components, modelling and forecasting trend, modelling and forecasting seasonality, characterising cycles in times series, forecasting cycles, Forecasting models with trend seasonality and cycle.

Unit III: Regression Modeling **(9 Hours)**

Simple linear regression and multiple linear regression models and their applications in business.

Unit IV: Some Related Concepts **(9 Hours)**

Stationary and non-stationary time series, Autoregressive (AR) Forecasting model, Moving average (MA) model, Autoregressive moving average model (ARMA), Autoregressive integrated moving average (ARIMA) model, Random walk model. Applications of these models in business.

Practical component (if any) – **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages

- Plot and visualize time series data.
- Fitting of trend by using Method of semi averages.
- Fitting of trend by Moving Average Method.
- Measurement of Seasonal indices using method of simple average.
- Measurement of Seasonal indices using Ratio-to-Trend method.
- Measurement of Seasonal indices using Ratio-to-Moving Average method.
- Measurement of seasonal indices using Link Relative method.
- To find cyclical variations using percentage of trend method and relative cyclical residual method.
- Fitting a simple linear regression model for forecasting.
- Fitting a multiple linear regression model for forecasting.

Essential/recommended readings

- Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (2008). *Forecasting methods and applications*. John wiley & sons.
- Pindyck, R. S., & Rubinfeld, D. L. (1976). *Econometric models and economic forecasts*. McGraw-Hill.
- Butler, W. F., Kavesh, R. A., & Platt, R. B. (Eds.). (1974). *Methods and techniques of business forecasting*. Prentice Hall.
- Diebold, F. X. (2004). *Elements of Forecasting*. Thompson: South Western. Ohio, USA.

Suggestive readings

- Hanke, J. E., & Wichern, D.W. (2014). *Business Forecasting.* Pearson.
- Gujarati, D. N. (2004). *Basic econometrics. (4th ed.),* McGraw-Hill.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CATEGORY-VI

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES

GENERIC ELECTIVES (GE): QUEUING AND RELIABILITY THEORY

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course
		Lecture	Tutorial	Practical/ Practice		
Queuing and Reliability Theory	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The Learning Objectives of this course are as follows:

- To make students understand the basic idea of random variables and their associated probability distributions as it is a prerequisite.
- To enrich students with the concept of stochastic processes and its applications in the field of queuing theory.
- To make students learn the mathematical theory of queuing systems.
- To introduce students with the concept of system reliability and make them learn to evaluate reliability of various system configurations.
- To provide students hands-on experience of the queuing and reliability models through practical sessions using certain software.

Learning outcomes

On successful completion of the course, students will be able to:

- Understand the concepts and mathematical theory related to queuing systems & system reliability required to understand, analyse and solve any real-world problem.

- Learn the concepts of stochastic processes, Markov processes, Markov chains and apply these mathematical models in real-life problems.
- Evaluate the performance metrics of any queuing system.
- Compute the system reliability of any type of system-configuration.
- Make use of software for problem analysis.

SYLLABUS

Unit I : Basic characteristics of a queueing system (12 Hours)
Kendall's notation, performance measures of a queueing system, Little's formula, Traffic intensity, Some general results for G/G/1 and G/G/c queueing models, Introduction to stochastic processes, Markov chain and Markov process, pure-birth process, pure-death process, birth-death process.

Unit II: Markovian queuing models (15 Hours)
single & multiple servers, finite & infinite system capacity, and finite & infinite population size, Cost analysis, Applications of queuing theory.

Unit III: Basic tools of Reliability (9 Hours)
Reliability function, and related concepts like hazard rate, mean time to failure (MTTF), classes of lifetime distributions, and hazard rate of Exponential and Weibull distributions.

Unit IV: System Reliability (9 Hours)
Reliability, hazard rate and MTTF of various system configurations- series, parallel, mixed configuration, k out of n system and stand-by system.

Practical component (if any) – (30 Hours)
Practical/Lab to be performed on a computer using OR/Statistical packages

- Finding measures of performance for deterministic queuing system.
- Finding measures of performance for M/M/1 queuing system with infinite capacity.
- Finding measures of performance for M/M/1 queuing system with finite capacity.
- Finding measures of performance for M/M/c queuing system with infinite capacity.
- Finding measures of performance for M/M/c queuing system with finite capacity.
- Finding measures of performance for any Markovian queuing system with multiple servers and with finite/infinite capacity.
- Measuring reliability of different types of system configuration.
- Measuring reliability, hazard rate and MTTF of different types of system configuration.

Essential/recommended readings

- Medhi J. (2009), *Stochastic Processes* (3rd Edition), New Delhi: New age science Ltd.
- Gross D., Shortle J. F, Thompson J. M., & Harris C. M. (2008), *Fundamentals of Queuing Theory* (4th edition), New Jersey: John Wiley & Sons, inc.
- Trivedi K. S. (2016), *Probability & Statistics with Reliability, Queuing & Computer Science applications*, New Jersey: John Wiley & Sons, Inc
- Srinath L. S., (2005), *Reliability Engineering*, New Delhi, East West Press.
- Rausand M. & Hoyland A. (2003), *System Reliability Theory: Models, Statistical Methods & Applications* (2nd ed.), New Jersey, John Wiley & Sons, Inc.

- Hiller F. S., Lieberman G. J., Nag B., Basu P. (2017). *Introduction to Operations Research- Concepts & Cases* (10th edition), New Delhi, Tata McGraw-Hill (Indian Print).
- Taha, H. A. (2019). *Operations Research-An Introduction* (10th ed.). New Delhi: Pearson Prentice Hall (Indian print).

Suggestive readings-Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DEPARTMENT OF STATISTICS
B. Sc. (H) Statistics
Category-I

DISCIPLINE SPECIFIC CORE COURSE-7: SAMPLE SURVEYS

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sample Surveys	4	3	0	1	Passed Class XII with Mathematics	Descriptive Statistics and probability theory

Learning Objectives:

The learning objectives of this course are to introduce:

- Tools and techniques for selecting a representative sample from a target population keeping in mind the objectives to be fulfilled.
- Obtain an estimator of the population parameter on the basis of the selected sample and study its properties.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the fundamental concepts of population and sample and the principles of sample survey
- Describe the value and methodologies for sample surveys versus other approaches to collecting information from populations.
- Determine the appropriate sample size and its allocation for nationwide sample surveys or for surveys to be conducted in a program area.
- Identify a proper sampling frame and select primary sample points.
- Apply steps involved in selecting a sample using Simple Random Sampling with or without replacement, Stratified Sampling, Systematic Sampling and Ratio and Regression Methods of Estimation

SYLLABUS OF DSC-7

Theory

UNIT I **(10 Hours)**

Basics of Survey Sampling

Concept of population and sample, complete enumeration versus sampling, sampling and non-sampling errors. Types of sampling: non-probability and probability sampling, basic principles of sample survey, Steps involved in survey sampling.

UNIT II **(8 Hours)**

Simple Random Sampling

Simple random sampling (SRS) with and without replacement, their properties, procedures of selecting a simple random sample, estimation of population mean and total, sampling for proportions, determination of sample size, bivariate population.

UNIT III **(10 Hours)**

Stratified Random Sampling

Stratified Random Sampling: Estimation of population mean and total, Allocation of sample in different strata using equal, proportional, optimum and Neyman allocations, comparison with SRS, practical difficulties in adopting Neyman allocation, estimation of gain in precision due to stratification.

UNIT IV **(7 Hours)**

Systematic Random Sampling

Systematic Random Sampling: Estimation of population mean and total, comparison with SRS and stratified sampling in the presence of linear trend, Yates' correction, definition of circular systematic sampling.

UNIT V **(10 Hours)**

Ratio and Regression Method of Estimation

Ratio method of estimation, first approximation to ratio estimator and its bias, first approximation to variance of ratio estimator, estimator of variance of ratio estimator, comparison of ratio with SRS.

Regression method of estimation, first approximation to linear regression estimator and its bias, first approximation to variance of the linear regression estimator, estimator of variance of the linear regression estimator, comparison with SRS and ratio estimator.

Practical -30 Hours

List of Practicals :

1. To select SRS with and without replacement.
2. For a population of size 5, estimate population mean, population mean square and population variance. Enumerate all possible samples of size 2 by WR and establish all properties relative to SRS.
3. For a population of size 5, estimate population mean, population mean square and population variance. Enumerate all possible samples of size 2 by WOR and establish all properties relative to SRS.
4. Estimate mean, standard error and the sample size for SRSWOR.
5. Stratified Sampling: allocation of sample to strata by proportional. Compare the efficiencies of above method relative to SRS.
6. Stratified Sampling: allocation of sample to strata by Neyman's methods. Compare the efficiencies of above method relative to SRS.
7. Estimation of gain in precision in stratified sampling.
8. Comparison of systematic sampling with stratified sampling and SRS in the presence of a linear trend and using end's correction.
9. Ratio estimation: Calculate the population mean or total of the population. Calculate mean squares. Compare the efficiency of ratio estimator relative to SRS.
10. Regression estimation: Calculate the population mean or total of the population.
11. Calculate mean squares. Compare the efficiency of regression estimator relative to SRS.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS

- Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9th Edition and 4th reprint.
- Cochran, W.G. (2011): Sampling Techniques (3rd Ed.), Wiley Eastern John Wiley and Sons.
- Sukhatme, P. V., Sukhatme, B. V., Sukhatme, S., Asok, C.(1984). Sampling Theories of Survey with Application, IOWA State University Press and Indian Society of Agricultural Statistics.

SUGGESTIVE READINGS:

- Gupta, S.C. and Kapoor, V.K. (2007): Fundamentals of Applied Statistics, Sultan Chand and Sons.
- Singh, D. and Chaudhary, F. S. (2015): Theory and Analysis of Sample Survey Designs.
- Murthy M.N. (1977): Sampling Theory & Statistical Methods, Statistical Pub. Society, Calcutta.
- Des Raj and Chandhok P. (1998): Sample Survey Theory, Narosa Publishing House.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE-8: ADVANCED PROBABILITY DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the Course			Eligibility Criteria	Pre-requisite of the Course (if any)
		Lecture	Tutorial	Practical/ Practice		
Advanced Probability Distributions	4	3	0	1	Passed Class XII with Mathematics	Theory of probability distributions

Learning Objectives

The learning objectives of this course are as follows:

- The course introduces students to advanced discrete and continuous probability distributions, and their important characteristics.
- It will enable them to understand the applications of these distributions.

Learning Outcomes

After successful completion of this course, students should be able to:

- Understand important advanced discrete probability distributions and their properties.
- Understand and apply important advanced continuous probability distributions and their properties.
- Apply their understanding of these distributions in real-life problems related to different areas of statistics.

SYLLABUS OF DSC-8

Theory

UNIT I **(15 hours)**

Discrete Probability Distributions

Negative Binomial Distribution: Probability distribution, particular cases, moment generating function, cumulants, limiting case, derivation of moments from binomial distribution and recurrence relation for probabilities of negative binomial distribution. Examples and applications based on the distribution. Hypergeometric Distribution: Probability distribution, mean, variance, approximation to Binomial Distribution and recurrence relation. Examples and applications based on the distribution. Geometric Distribution: Probability distribution, lack of memory property, moments and moment generating function. Examples and applications based on the distribution. Multinomial Distribution: Probability distribution and practical application.

UNIT II **(15 hours)**

Continuous Probability Distributions

Rectangular or Uniform Distribution: Definition, probability distribution and cumulative probability distribution, moments, and moment generating function, characteristic function and mean deviation about mean. Examples and applications based on the distribution. Gamma Distribution: Definition and properties, probability distribution, mean, variance, moment generating function, cumulant generating function, additive property and limiting case. Examples and applications based on the distribution. Beta Distribution: Beta Distribution of the first kind: Definition, probability distribution and cumulative probability distribution, mean, variance and harmonic mean. Beta Distribution of the second kind: Definition, probability distribution, mean, variance and harmonic mean. Examples and applications based on the distributions.

UNIT III **(15 hours)**

Continuous Probability Distributions (contd.)

Exponential Distribution: Definition, probability distribution and cumulative probability distribution, moment generating function, mean, variance and lack of memory property. Examples and applications based on the distribution. Standard Laplace (Double Exponential) Distribution: Definition, probability distribution, characteristic function and moments. Two Parameter Laplace Distribution: Definition, probability distribution, characteristic function and moments. Examples and applications based on the distribution. Weibull Distribution: Probability distribution, moments and practical applications. Logistic Distributions: Probability distribution, moments and practical applications. Cauchy Distribution: Definition, probability distribution, characteristics function, additive property and moments. Examples and applications based on the distribution.

PRACTICAL – 30 Hours

List of Practicals:

Practicals based on:

1. Application of Negative Binomial Distribution.

2. Fitting of Negative Binomial Distribution.
3. Application of Hypergeometric Distribution
4. Fitting of Geometric Distribution.
5. Lack of memory property of Geometric Distribution
6. Applications of
   (a) Geometric Distribution.
   (b) Multinomial Distribution.
   (c) Rectangular Distribution
   (d) Gamma Distribution
   (e) Beta Distribution.
   (f) Exponential Distribution.
   (g) Weibull Distribution.
   (h) Logistic Distribution.
   (i) Cauchy Distribution.
7. Lack of memory property of Exponential Distribution.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS.

ESSENTIAL READINGS

- Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, Twelfth Edition, Sultan Chand and Sons, Delhi.
- Ross, Sheldon M. (2013): A First Course in Probability, Ninth Edition, Pearson.
- Miller, I. and Miller, M. (2006). John E. Freund's Mathematical Statistics with Applications, Eight Edition., Pearson Education, Asia.
- Mood, A.M. Graybill, F.A. and Boes, D.C. (2007). Introduction to the Theory of Statistics, Third Edition, (Reprint), Tata McGraw-Hill Pub. Co. Ltd.

SUGGESTED READINGS

- Rohatgi, V. K and Saleh M. E. (2015). An Introduction to Probability and Statistics, Third Edition, John Wiley and Sons, Inc., New Jersey.
- Hogg, R.V., Tanis, E.A. and Rao, J.M. (2009). Probability and Statistical Inference, 7th Ed., Pearson Education, New Delhi.
- Ross, Sheldon M.(2009). Introduction to Probability and Statistics for Engineers and Scientists, Fourth Edition, Academic Press.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 9: MATHEMATICAL ANALYSIS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Analysis-DSC-09	4	3	0	1	**Passed Class XII with Mathematics**	Nil

Learning Objectives

The learning objectives include:

- To study Real Analysis, which deals with the analytical properties of real functions and sequences.
- To study Numerical Analysis, which is the study of algorithms that use numerical approximation for the problems of mathematical analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

· Understand the fundamental properties of real numbers and real-valued functions.
· Understand the Analytical properties of sequences.
· Apply Infinite series, their properties and different tests.
· Apply limits, continuity, differentiability, and mean value theorems.
· Use the fundamentals of numerical analysis, interpolation, numerical integration and difference equation.

SYLLABUS OF DSC-9

Theory

UNIT I **(10 hours)**

Set Theory and Sequences

Completeness: The Completeness property of R; Archimedean property in R; Neighbourhood and limit points: Neighbourhood, Open Set, Closed Set, Supremum and Infimum, Limit Point of a Set; Sequences: Definition of a Sequence, Convergent Sequence, Divergent Sequence, Oscillatory Sequence, Cauchy Sequence, Monotone Sequence.

UNIT II **(10 hours)**

Series

Infinite series, positive termed series and their convergence, Comparison test, D'Alembert's ratio test, Cauchy's n^{th} root test, Raabe's test. Gauss test, Cauchy's condensation test and integral test (Statements and Examples only). Absolute convergence of series, Conditional convergence.

UNIT III **(10 hours)**

Limit and Continuity

Review of limit, continuity and differentiability, uniform Continuity and boundedness of a function. Rolle's and Lagrange's Mean Value theorems. Taylor's theorem with Lagrange's and Cauchy's form of remainder (without proof). Taylor's and Maclaurin's series expansions of sin(x), cos(x), log (1+x).

UNIT IV (15 hours)

Numerical Methods

Factorial, finite differences and interpolation. Operators, E and divided difference. Newton's forward, backward and divided differences interpolation formulae. Lagrange's interpolation formulae. Gauss and Stirling interpolation formulae. Numerical integration. Trapezoidal rule, Simpson's one-third rule, three-eights rule, Stirling's approximation to factorial n. Solution of difference equations of first order, Euler Maclaurin's summation formula.

PRACTICAL/LAB WORK – (30 hours)

List of Practical:

Practicals based on:

1. Formation of difference table, fitting of polynomial and missing terms for equal interval of differencing.
2. Newton's Gregory forward difference interpolation formula.
3. Newton's backward difference interpolation formula.
4. Newton's divided difference and Lagrange's interpolation formula.
5. Gauss forward, Gauss backward central difference interpolation formula.
6. Stirling's central difference interpolation formula.
7. Lagrange's Inverse interpolation formula.
8. Method of successive approximation or iteration.
9. Method of reversion of series.
10. Trapezoidal Rule, Simpson's one-third rule, Simpson's three-eighth rule, Weddle's rule.
11. Euler-Maclaurin summation formula

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS

- Appostol, T.M. (1987). Mathematical Analysis, 2nd Ed., Narosa Publishing House,New Delhi
- Ghorpade, S.R. and Limaye, B.V. (2006). A Course in Calculus and Real Analysis, Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint.
- Sastry, S.S. (2000). Introductory Methods of Numerical Analysis, 3rd Ed., Prentice Hall of India Pvt. Ltd., New Delhi.

SUGGESTIVE READINGS:

- Bartle, R.G. and Sherbert, D.R. (2002). Introduction to Real Analysis, (3rd Ed.,), John Wiley and Sons (Asia) Pte. Ltd., Singapore.
- Jain, M.K., Iyengar, S.R.K. and Jain, R.K. (2003). Numerical methods for scientific and engineering computation, New age International Publisher, India.
- Malik, S.C. and Arora, S. (1994). Mathematical Analysis, Second Edition, Wiley Eastern Limited, New Age International Limited, New Delhi.
- Mukherjee, Kr. Kalyan (1990). Numerical Analysis. New Central Book Agency.
- Narayan, S. (1987). A course of Mathematical Analysis, 12th revised Ed., S. Chand &Co. (Pvt.) Ltd., New Delhi.

● Somasundram, D. and Chaudhary, B. (1987). A First Course in Mathematical Analysis, Narosa Publishing House, New Delhi.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

B.SC. (P)/B.A(P) WITH STATISTICS AS MAJOR

Category II

DISCIPLINE SPECIFIC CORE COURSE – 1: SAMPLING DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sampling Distributions	4	3	0	1	**Passed Passed Class XII with Mathematics**	Statistical Methods

Learning Objectives:

The learning objectives include:

- To understand the concept of sampling distributions and their applications in statistical inference.
- To understand the process of hypothesis testing.
- To have a clear understanding of when to apply various tests of hypothesis about population parameters using sample statistics and draw appropriate conclusions from the analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the basic concepts of hypothesis testing, including framing of the null and alternative hypotheses.
- Apply hypothesis testing based on a single sample and two samples using both classical and p-value approaches.
- Understand the Chi-square distribution.
- Analyze categorical data by using Chi-square techniques.
- Apply t and F distributions

SYLLABUS OF DSC-5

Theory

Unit I **(15 hours)**

Large sample tests

Large sample tests: Definitions of a random sample, parameter, and statistic, sampling distribution of a statistic, sampling distribution of the sample mean, standard errors of the sample mean, and the sample proportion. Null and alternative hypotheses, level of significance, Type I and Type II errors, their probabilities and critical region. Large sample tests, use of CLT for testing single proportion, difference of two proportions, single mean, difference of two means, standard deviation and difference of standard deviations by classical and p-value approaches.

Unit II **(15 hours)**

Chi-square distribution

Chi-square distribution: Definition and derivation of $\chi 2$ distribution with n degrees of freedom (d.f.) using m.g.f., nature of probability curve for different degrees of freedom, mean, variance, m.g.f., cumulant generating function, mode, additive property and limiting form of $\chi 2$ distribution. Tests of significance and confidence intervals based on χ^2 distribution.

Unit III **(15 hours)**

Exact Sampling Distributions

t and F distributions: Student's t and Fishers t-distributions, Derivation of its p.d.f., nature of probability curve with different degrees of freedom, mean, variance, moments and limiting form of t distribution. Snedecore's F-distribution: Derivation of F distribution, nature of probability curve with different degrees of freedom, mean, variance and mode. Distribution of $1/F(n_1,n_2)$. Relationship between t, F and $\chi 2$ distributions. Test of significance and confidence intervals based on t and F distributions.

PRACTICAL/LAB WORK - 30 hours

List of Practicals

1. Large Sample Tests:
   a) Testing of significance and confidence intervals for single proportion and difference of two proportions.
   b) Testing of significance and confidence intervals for single mean and difference of two means.
   c) Testing of significance and confidence intervals for difference of two standard deviations.
2. Tests based on Chi-Square Distribution:
   a) To test if the population variance has a specific value and its confidence intervals.
   b) To test the goodness of fit.
   c) To test the independence of attributes.
   d) Test based on 2 x 2 contingency table without and with Yates' corrections.
3. Tests based on t- Distribution and F- Distribution:
   a) Testing of significance and confidence intervals for single mean and difference of two means and paired t – test.
   b) Testing of significance and confidence intervals of an observed sample correlation coefficient.
   c) Testing and confidence intervals of equality of two population variances.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS :

● Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, 12th Ed., S. Chand and Sons. Delhi.

● Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9th Edition and 4th reprint.

● Rohatgi, V. K. and Saleh, A.K. Md. E. (2009). An Introduction to Probability and Statistics, 2nd Ed., (Reprint) John Wiley and Sons.

SUGGESTIVE READINGS:

● Hogg, R.V. and Tanis, E.A. (2009). A Brief Course in Mathematical Statistics. Pearson Education.

● Mood, M.A., Graybill, F.A. and Boes, C.D. (2007). Introduction to the Theory of Statistics, 3rd Ed., (Reprint).Tata McGraw-Hill Pub. Co. Ltd.
● Johnson, R.A. and Bhattacharya, G.K. (2001). Statistics-Principles and Methods, 4th Ed., John Wiley and Sons.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 6: STATISTICAL QUALITY CONTROL

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Statistical Quality Control	4	3	0	1	**Passed Class XII with Mathematics**	Statistical Methods

Learning Objectives

The learning objectives include:

- This course will help students to learn techniques and approaches of SQC being used in industry to manufacture goods and services of high quality at low cost.
- This course will also give exposure to sampling inspection plans.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Comprehend the concept of Statistical Quality Control and its application in Industry.
- Apply Statistical process control tools- Control charts for variables, and attributes.
- Analyse different patterns of variation on Control charts
- Apply statistical product control tools- Sampling inspection plans.

SYLLABUS OF DSC-6

Theory

UNIT I: **(9 hours)**

Basics of Quality

Definition, dimensions of quality, its concept, application, and importance. Introduction to Process and Product Control. Statistical Process Control - Seven tools of SPC, Chance and Assignable Causes of quality variation.

UNIT II: **(21 hours)**

Statistical Control Charts

Construction and Statistical basis of 3-σ Control charts, Control charts for variables: $\underline{X}$& R-chart, $\underline{X}$ & s-chart. chart (for known and unknown parameters) Control charts for attributes:

np-chart, p-chart, c-chart (for known and unknown parameters). Revised control limits. Comparison between control charts for variables and control charts for attributes. Analysis of patterns on control chart. Differentiate between Control Limits, Specification Limits and Natural Tolerance Limits. Concept of process capability.

UNIT III: (15 hours)

Acceptance sampling plan

Principle of acceptance sampling plans. Single sampling plan its OC, AQL, LTPD, AOQ, AOQL, ASN, ATI functions with graphical interpretation. Introduction to Dodge and Romig's sampling inspection plan tables.

PRACTICAL/LAB WORK - (30 hours)

List of Practical:

1. Construction and interpretation of statistical control charts for
a) $\underline{X}$ and R-chart
b) $\underline{X}$ *and* s-chart
c) np-chart
d) p-chart
e) c-chart
2. Single sample inspection plan: Construction and interpretation of OC, AQL, LTPD, ASN, ATI, AOQ, AOQL curves.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS

- Montgomery, D. C. (2009). Introduction to Statistical Quality Control, 6th Ed., Wiley India Pvt. Ltd.
- Goon, A.M., Gupta, M.K. and Dasgupta, B. (2002). Fundamentals of Statistics, Vol. I & II, 8th Ed., The World Press, Kolkata.

SUGGESTIVE READINGS:

- Gupta, S.C. and Kapoor, V.K. (2014). Fundamentals of Mathematical Statistics, 11th Ed., Sultan Chand.
- Mukhopadhyay, P (2011): Applied Statistics, 2nd edition revised reprint, Books and Allied(P) Ltd

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

B.Sc. (P)/B.A(P) with Statistics as Non-Major
Category III

DISCIPLINE SPECIFIC CORE COURSE – 3: SAMPLING DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sampling Distributions	4	3	0	1	**Passed Class XII with Mathematics**	Statistical Methods

Learning Objectives:

The learning objectives include:

- To understand the concept of sampling distributions and their applications in statistical inference.
- To understand the process of hypothesis testing.
- To have a clear understanding of when to apply various tests of hypothesis about population parameters using sample statistics and draw appropriate conclusions from the analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the basic concepts of hypothesis testing, including framing of the null and alternative hypotheses.
- Apply hypothesis testing based on a single sample and two samples using both classical and p-value approaches.
- Understand the Chi-square distribution.
- Analyze categorical data by using Chi-square techniques.
- Apply t and F distributions

SYLLABUS OF DSC-3

Theory

Unit I **(15 hours)**

Large sample tests

Large sample tests: Definitions of random sample, parameter and statistic, sampling distribution of a statistic, sampling distribution of sample mean, standard errors of sample mean, and sample proportion. Null and alternative hypotheses, level of significance, Type I and Type II errors, their probabilities and critical region. Large sample tests, use of CLT for testing single proportion, difference of two proportions, single mean, difference of two means, standard deviation and difference of standard deviations by classical and p-value approaches.

Unit II **(15 hours)**

Chi square distribution

Chi square distribution: Definition and derivation of $\chi 2$ distribution with n degrees of freedom

(d.f.) using m.g.f., nature of probability curve for different degrees of freedom, mean, variance, m.g.f., cumulant generating function, mode, additive property and limiting form of $\chi 2$ distribution. Tests of significance and confidence intervals based on $\chi 2$ distribution.

Unit III **(15 hours)**

Exact Sampling Distributions

t and F distributions: Student's t and Fishers t-distributions, Derivation of its p.d.f., nature of probability curve with different degrees of freedom, mean, variance, moments and limiting form of t distribution. Snedecore's F-distribution: Derivation of F distribution, nature of probability curve with different degrees of freedom, mean, variance and mode. Distribution of $1/F(n_1,n_2)$. Relationship between t, F and $\chi 2$ distributions. Test of significance and confidence intervals based on t and F distributions.

PRACTICAL/LAB WORK - (30 hours)

List of Practicals

1. Large Sample Tests:

(i) Testing of significance and confidence intervals for single proportion and difference of two proportions.

(ii) Testing of significance and confidence intervals for single mean and difference of two means.

(iii) Testing of significance and confidence intervals for the difference of two standard deviations.

2. Tests based on Chi-Square Distribution:

(i) To test if the population variance has a specific value and its confidence intervals.

(ii) To test the goodness of fit.

(iii) To test the independence of attributes.

(iv) Test based on 2 x 2 contingency table without and with Yates' corrections.

3. Tests based on t- Distribution and F- Distribution:

(i) Testing of significance and confidence intervals for single mean and difference of two means and paired t – test.

(ii) Testing of significance and confidence intervals of an observed sample correlation coefficient.

(iii) Testing and confidence intervals of equality of two population variances.

ESSENTIAL READINGS :

- Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, 12th Ed., S. Chand and Sons. Delhi.
- Rohatgi, V. K. and Saleh, A.K. Md. E. (2009). An Introduction to Probability and Statistics, 2nd Ed., (Reprint) John Wiley and Sons.
- Goon, A.M., Gupta, M.K. and Dasgupta, B. (2003). An Outline of Statistical Theory, Vol. I, 4th Ed., World Press, Kolkata.

SUGGESTIVE READINGS:

- Hogg, R.V. and Tanis, E.A. (2009). A Brief Course in Mathematical Statistics. Pearson Education.
- Mood, M.A., Graybill, F.A. and Boes, C.D. (2007). Introduction to the Theory of Statistics, 3rd Ed., (Reprint).Tata McGraw-Hill Pub. Co. Ltd.
- Johnson, R.A. and Bhattacharya, G.K. (2001). Statistics-Principles and Methods, 4th Ed., John Wiley and Sons.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Discipline Specific Elective
Category-V
Discipline Specific Elective for B. Sc. (H) Statistics

DISCIPLINE SPECIFIC ELECTIVE COURSE-1A: Optimization Techniques

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Operational Research	4	3	0	1	**Passed Class XII with Mathematics**	**Nil**

Learning Objectives:

The learning objectives include:

- To create awareness about the term operational research (OR) and acquaint them with the methodologies, scope, limitations and applications of OR and
- To expose the students with the knowledge of formulation of real life problems using the linear programming method.
- To make the students understand about the theory and practical application of transportation problems and assignment problems
- To introduce 'Game Theory-the science of strategy' to the students, which makes possible the analysis of the decision making process of interdependent subjects.
- To provide a framework to develop mathematical models for different types inventory systems.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the fundamental concepts of Operational Research Techniques
- Apply Linear Programming.
- Solve the Transportation and assignment problems
- Understand the Game Theory
- Use the Inventory Models

SYLLABUS OF DSE-1A

Theory

UNIT I **(15 hours)**

Introduction to OR and LPP

Definition and phases of O.R. Model building, various types of O.R. problems. Linear Programming Problem (L.P.P.): Mathematical formulation of the L.P.P, graphical solutions of L.P.P. Simplex method for solving L.P.P. Charne's M-technique for solving L.P.P. involving artificial variables. Special cases of L.P.P. Concept of Duality in L.P.P. Economic interpretation of Duality. Dual simplex method.

UNIT II **(15 hours)**

Transportation and Assignment Problem

Transportation Problem: Initial solution by North West corner rule, Least cost method and Vogel's approximation method (VAM), MODI's method to find the optimal solution, special cases of transportation problem. Assignment problem: Hungarian method to find optimal assignment, special cases of assignment problem.

UNIT III **(15 hours)**

Game Theory and Inventory Management

Game theory: Rectangular game, minimax - maximin principle, solution to rectangular game using graphical method, dominance and modified dominance property to reduce the game matrix and solution to rectangular game with mixed strategy. Network flow problems and shortest route problem. Inventory Management: ABC inventory system, characteristics of inventory system. EOQ Model and its variations, with and without shortages.

PRACTICAL/LAB WORK – (30 hours)

List of Practical:

1. Mathematical formulation of L.P.P and solving the problem using graphical method.
2. Simplex technique and Charne's Big M method involving artificial variables.
3. Identifying Special cases by Graphical and Simplex method and interpretation:
   a) Degenerate solution
   b) Unbounded solution
   c) Alternate solution
   d) Infeasible solution
4. Allocation problem using Transportation model.
5. Allocation problem using Assignment model.
6. Graphical solution to $mx2$ / $2xn$ rectangular game
7. Mixed strategy
8. To find optimal inventory policy for EOQ models and its variations.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators/ TORA/WINQSB/LINGO

ESSENTIAL READINGS:

- Swarup, K., Gupta, P.K. and Man Mohan (2013). Operations Research, 16th Ed., Sultan Chand and Sons.
- Taha, H. A. (2007). Operations Research: An Introduction, 8thEd., Prentice Hall of India.

SUGGESTIVE READINGS:

- F.S. Hillier. G.J. Lieberman (2010). Introduction to Operations Research- Concepts and Cases, 9th Edition, Tata McGraw Hill.
- Donald Waters (2010): Inventory Control and Management, John Wiley.
- A. Ravindran, D. T. Phillips and James J. Solberg(2005). Operations Research- Principles and Practice, John Wiley & Sons,
- G. Hadley (2002). Linear Programming, Reprint.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE – 1B: PSYCHOLOGICAL AND EDUCATIONAL STATISTICS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Psychological and Educational Statistics	4	3	0	1	**Passed Class XII with Mathematics**	**Theory of Probability Distributions**

Learning Objectives:

The learning objectives include:

- To measure psychological traits and mental abilities
- To learn basic methods of test construction, item writing and item analysis
- To check the reliability and validity of test scores.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Distinguish between Psychological measurement and physical measurement.
- Understand the meaning of Tests in Psychology and Education.
- Appreciate the uses and limitations of Psychological tests.
- Learn the meaning and purpose of Item writing and analysis.
- Understand concepts of reliability and validity of test scores and their differences.
- Convert raw scores into different transformed scores.
- Apply Scaling rankings and ratings in terms of the Normal Probability Curve.

SYLLABUS OF DSE-1B

Theory

Unit I **(15 hours)**

Basics of Educational Statistics

Introduction; need and importance of statistics in psychology and education. Measurements: Levels of measurements. Distinction between psychological and physical measurements; general problems, sources of errors. Tests: Meaning of tests in psychology and education; history of psychological measurement and testing, uses, limitations and varieties, characteristics of a good test, general steps of test construction. Test administration. Item writing - Meaning and types; Item analysis – meaning and purpose. Item difficulty (concepts only). Power tests and speed tests.

Unit II **(15 hours)**

Reliability and Validity

Reliability: Meaning, methods (or types); standard error of measurement, reliability of speed test, factors influencing reliability of test scores, factors for their improvement, estimation of true scores and index of reliability. Reliability of difference and composite scores. Validity:

Meaning; content, criterion related and construct validity. Statistical methods for calculating validity, factors influencing validity. Extra validity concerns, relation of validity to reliability.

Unit III **(15 hours)**

Psychological Statistics

Meaning of norm referencing and criterion referencing. Raw score transformations- percentile score, standard scores, normalized standard scores, T-scores, C-scores and Stanine scores. Intelligence: Definition. Types of intelligence test scores. Spearman's two-factor theory and Thomson group factors theory. Psychological scaling methods – Scaling of Individual test items in terms of difficulty, scaling of rankings & ratings in terms of the normal probability curve.

PRACTICAL/LAB WORK - 30 hours

List of Practical:

1. Computation of Reliability by Rulon and Kuder Richardson Formulas.
2. Finding reliability of a test whose length is increased/ decreased n times.
3. Finding index of reliability, standard error of measurement.
4. Finding validity/maximum validity when test length is increased n times/ indefinitely.
5. Finding relative difficulty of questions/ difference in difficulty between different tests.
6. Converting raw scores into Z-scores.
7. Converting raw scores into T-scores.
8. Calculation of T scores for a given frequency distribution.
9. Construction of C-scales and its diagrammatic representation.
10. Construction of Stanine-scales and its diagrammatic representation.
11. Calculation of percentile scores corresponding to rank of an individual among N individuals.
12. Finding numerical scores corresponding to grades or ratings by different judges.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS:

- Garrett H. E. (2021). Statistics in psychology and education. Nation Press.
- Gregory R. J. (2016). Psychological testing: History Principles and Applications. (Updated seventh). Pearson.
- Singh, A. K. (2006). Tests, Measurements and Research in Behavioural Sciences. Bharati Bhavan.
- Anastasi A. & Urbina S. (1997). Psychological testing (7th ed.). Prentice Hall.

SUGGESTIVE READINGS:

- Gupta, S. C., & Kapoor, V. K. (2019). Fundamentals of applied statistics. Sultan Chand & Sons.
- Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9th Edition and 4th reprint.
- Mangal, S. K. (2016). Statistics in Psychology and Education. PHI Learning Pvt. Ltd..

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE FOR B. SC. (P)

DISCIPLINE SPECIFIC ELECTIVE COURSE – 1: TIME SERIES ANALYSIS AND INDEX NUMBERS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Time Series Analysis and Index Numbers	4	3	0	1	**Passed Class XII with Mathematics**	**Descriptive Statistics and Probability Theory**

Learning Objectives

The Learning Objectives of this course are as follows:

- Introduce the concept of time series, its components, and their estimation.
- Introduce the application of time series.
- Introduce the concept, formulation, and application of index numbers.

Learning outcomes

After completion of this course, the students will be able to:

- Understand the concepts of time series and index numbers.
- Formulate, solve, and analyse the use of time series and index numbers for real-world problems.

SYLLABUS OF DSE 1

Theory

Unit - 1 **(12 hours)**

Components of Time Series

Introduction to Time Series, Components of time series, Decomposition of time series- Additive and multiplicative model with their merits and demerits, Illustrations of time series, Measurement of trend by method of free-hand curve, method of semi-averages and method of least squares (linear, quadratic and exponential).

Unit - 2 **(15 hours)**

Trend and Seasonality

Fitting of modified exponential, Gompertz and logistic curve, Moving average method, Measurement of seasonal variations by method of simple averages, ratio to trend method, and ratio to moving average method.

Unit - III **(18 hours)**

Index Numbers

Introduction to Index numbers, Problems in the construction of index numbers, Construction of price and quantity index numbers: simple aggregate, weighted aggregate (Laspeyres, Paasche's, Drobish-Bowley, Marshall-Edgeworth's, Walsch and Fisher's Formula), simple and weighted

average of price relatives, and chain base method, Criteria for a good index number, Errors in the measurement of price and quantity index numbers, Consumer price index number, its construction and uses, Uses and limitations of index numbers.

Practical - 30 Hours
List of Practicals:

1. Fitting of linear trend
2. Fitting of quadratic trend
3. Fitting of an exponential curve
4. Fitting of modified exponential curve by the method of
    a. Three selected points
    b. Partial sums
5. Fitting of Gompertz curve by the method of
    a. Three selected points
    b. Partial sums
6. Fitting of logistic curve by the method of three selected points
7. Fitting of trend by moving average method (for n even and odd)
8. Measurement of seasonal indices by
    a. Method of simple averages
    b. Ratio-to-trend method
    c. Ratio-to-moving-average method
9. Construction of price and quantity index numbers by simple aggregate method.
10. Construction of price and quantity index numbers by Laspeyres, Paasche's, Drobish-Bowley, Marshall-Edgeworth, Walsch and Fisher's Formula.
11. Construction of price and quantity index numbers by simple and weighted average of price relatives.
12. Construction of index number by Chain base method.
13. Construction of consumer price index number by
    a. Family budget method
    b. Aggregate expenditure method
14. Time Reversal Test and Factor Reversal Test

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS

- Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9th Edition and 4th reprint.
- Gupta, S.C. and Kapoor, V.K. (2014). Fundamentals of Applied Statistics, 11th Ed., Sultan Chand.
- Croxton, Fredrick E, Cowden, Dudley J. and Klein, S. (1973): Applied General Statistics, 3rd edition, Prentice Hall of India Pvt. Ltd.

SUGGESTIVE READING

- Mukhopadhyay, P. (1999). Applied Statistics, New Central Book Agency, Calcutta.
- Allen R.G.D. (1975): Index Numbers in Theory and Practice, Macmillan

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES
OFFERED BY DEPARTMENT OF STATISTICS
CATEGORY-VI

GENERIC ELECTIVES – : SAMPLING DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sampling Distributions	4	3	0	1	**Passed Class XII with Mathematics**	Introductory Probability

Learning Objectives:

The learning objectives include:

- To understand the concept of sampling distributions and their applications in statistical inference.
- To understand the process of hypothesis testing.
- To have a clear understanding of when to apply various tests of hypothesis about population parameters using sample statistics and draw appropriate conclusions from the analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the basic concepts of hypothesis testing, including framing of the null and alternative hypotheses.
- Apply hypothesis testing based on a single sample and two samples using both classical and p-value approaches.
- Understand the Chi-square distribution.
- Analyze categorical data by using Chi-square techniques.
- Apply t and F distributions

SYLLABUS OF GE-3A

Theory

Unit I **(15 hours)**

Large sample tests

Large sample tests: Definitions of random sample, parameter and statistic, sampling distribution of a statistic, sampling distribution of sample mean, standard errors of sample mean, and sample proportion. Null and alternative hypotheses, level of significance, Type I

and Type II errors, their probabilities and critical region. Large sample tests, use of CLT for testing single proportion, difference of two proportions, single mean, difference of two means, standard deviation and difference of standard deviations by classical and p-value approaches.

Unit II **(15 hours)**

Chi square distribution

Chi square distribution: Definition and derivation of $\chi 2$ distribution with n degrees of freedom (d.f.) using m.g.f., nature of probability curve for different degrees of freedom, mean, variance, m.g.f., cumulant generating function, mode, additive property and limiting form of $\chi 2$ distribution. Tests of significance and confidence intervals based on $\chi 2$ distribution.

Unit III **(15 hours)**

Exact Sampling Distributions

t and F distributions: Student's t and Fishers t-distributions, Derivation of its p.d.f., nature of probability curve with different degrees of freedom, mean, variance, moments and limiting form of t distribution. Snedecore's F-distribution: Derivation of F distribution, nature of probability curve with different degrees of freedom, mean, variance and mode. Distribution of $1/F(n_1,n_2)$. Relationship between t, F and $\chi 2$ distributions. Test of significance and confidence intervals based on t and F distributions.

PRACTICAL/LAB WORK - 30 hours

List of Practicals

1. Large Sample Tests:

(i) Testing of significance and confidence intervals for single proportion and difference of two proportions.

(ii) Testing of significance and confidence intervals for single mean and difference of two means.

(iii) Testing of significance and confidence intervals for difference of two standard deviations.

2. Tests based on Chi-Square Distribution:

(i) To test if the population variance has a specific value and its confidence intervals.

(ii) To test the goodness of fit.

(iii) To test the independence of attributes.

(iv) Test based on 2 x 2 contingency table without and with Yates' corrections.

3. Tests based on t- Distribution and F- Distribution:

(i) Testing of significance and confidence intervals for single mean and difference of two means and paired t – test.

(ii) Testing of significance and confidence intervals of an observed sample correlation coefficient.

(iii) Testing and confidence intervals of equality of two population variances.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS :

- Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, 12th Ed., S. Chand and Sons. Delhi.
- Goon, A.M., Gupta, M.K. and Dasgupta, B. (2003). An Outline of Statistical Theory, Vol. I, 4th Ed., World Press, Kolkata.

● Rohatgi, V. K. and Saleh, A.K. Md. E. (2009). An Introduction to Probability and Statistics, 2nd Ed., (Reprint) John Wiley and Sons.

SUGGESTIVE READINGS:

● Hogg, R.V. and Tanis, E.A. (2009). A Brief Course in Mathematical Statistics. Pearson Education.
● Mood, M.A., Graybill, F.A. and Boes, C.D. (2007). Introduction to the Theory of Statistics, 3rd Ed., (Reprint).Tata McGraw-Hill Pub. Co. Ltd.
● Johnson, R.A. and Bhattacharya, G.K. (2001). Statistics-Principles and Methods, 4th Ed., John Wiley and Sons.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Major 1/ Minor 1: Descriptive Statistics and Probability Theory
Major 3/ Minor 2: Statistical Methods
GE -2A: Introductory Probability

DEPARTMENT OF MATHEMATICS

B.Sc. (Hons) MATHEMATICS

Category-I

DISCIPLINE SPECIFIC CORE COURSE -7: GROUP THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Group Theory	4	3	1	0	Class XII pass with Mathematics	Algebra

Learning Objectives

The primary objective of this course is to introduce:

- Symmetric groups, normal subgroups, factor groups, and direct products of groups.
- The notions of group homomorphism to study the isomorphism theorems with applications.
- Classification of groups with small order according to isomorphisms.

Learning Outcomes

This course will enable the students to:

- Analyse the structure of 'small' finite groups, and examine examples arising as groups of permutations of a set, symmetries of regular polygons.
- Understand the significance of the notion of cosets, Lagrange's theorem and its consequences.
- Know about group homomorphisms and isomorphisms and to relate groups using these mappings.
- Express a finite abelian group as the direct product of cyclic groups of prime power orders.
- Learn about external direct products and its applications to data security and electric circuits.

SYLLABUS OF DSC - 7

Unit – 1 **(18 hours)**

Permutation Groups, Lagrange's Theorem and Normal Subgroups

Permutation groups and group of symmetries, Cycle notation for permutations and properties, Even and odd permutations, Alternating groups; Cosets and its properties, Lagrange's theorem and consequences including Fermat's Little theorem, Number of elements in product of two finite subgroups; Normal subgroups, Factor groups, Cauchy's theorem for finite Abelian groups.

Unit – 2 **(15 hours)**

Group Homomorphisms and Automorphisms

Group homomorphisms, isomorphisms and properties, Cayley's theorem; First, Second and Third isomorphism theorems for groups; Automorphism, Inner automorphism, Automorphism

groups, Automorphism groups of cyclic groups, Applications of factor groups to automorphism groups.

Unit – 3 **(12 hours)**

Direct Products of Groups and Fundamental Theorem of Finite Abelian Groups

External direct products of groups and its properties, The group of units modulo n as an external direct product, Applications to data security and electric circuits; Internal direct products; Fundamental theorem of finite abelian groups and its isomorphism classes.

Essential Reading

1. Gallian, Joseph. A. (2017). Contemporary Abstract Algebra (9th ed.). Cengage Learning India Private Limited, Delhi. Indian Reprint 2021.

Suggestive Readings

- Artin, Michael. (1991). Algebra (2nd ed.). Pearson Education. Indian Reprint 2015.
- Dummit, David S., & Foote, Richard M. (2016). Abstract Algebra (3rd ed.). Student Edition. Wiley India.
- Herstein, I. N. (1975). Topics in Algebra (2nd ed.). Wiley India, Reprint 2022.
- Rotman, Joseph J. (1995). An Introduction to The Theory of Groups (4th ed.). Springer-Verlag, New York.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE -8: RIEMANN INTEGRATION

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Riemann Integration	4	3	1	0	Class XII pass with Mathematics	Elementary Real Analysis, and Calculus

Learning Objectives

The primary objective of this course is to:

- Understand the integration of bounded functions on a closed and bounded interval and its extension to the cases where either the interval of integration is infinite, or the integrand has infinite limits at a finite number of points on the interval of integration.
- Learn some of the properties of Riemann integrable functions, its generalization and the applications of the fundamental theorems of integration.
- Get an exposure to the utility of integration for practical purposes.

Learning Outcomes

This course will enable the students to:

- Learn about some of the classes and properties of Riemann integrable functions, and the applications of the Riemann sums to the volume and surface of a solid of revolution.
- Get insight of integration by substitution and integration by parts.
- Know about convergence of improper integrals including, beta and gamma functions.

SYLLABUS OF DSC - 8

Unit – 1 **(18 hours)**

The Riemann Integral

Definition of upper and lower Darboux sums, Darboux integral, Inequalities for upper and lower Darboux sums, Necessary and sufficient conditions for the Darboux integrability; Riemann's definition of integrability by Riemann sum and the equivalence of Riemann's and Darboux's definitions of integrability; Definition and examples of the Riemann-Stieltjes integral.

Unit – 2 **(15 hours)**

Properties of The Riemann Integral and Fundamental Theorems

Riemann integrability of monotone functions and continuous functions, Properties of Riemann integrable functions; Definitions of piecewise continuous and piecewise monotone functions and their Riemann integrability; Intermediate value theorem for integrals, Fundamental Theorems of Calculus (I and II).

Unit – 3 **(12 hours)**

Applications of Integrals and Improper Integrals

Methods of integration: integration by substitution and integration by parts; Volume by slicing and cylindrical shells, Length of a curve in the plane and the area of surfaces of revolution. Improper integrals of Type-I, Type-II and mixed type, Convergence of improper integrals, The beta and gamma functions and their properties.

Essential Readings

1. Ross, Kenneth A. (2013). Elementary Analysis: The Theory of Calculus (2nd ed.). Undergraduate Texts in Mathematics, Springer.
2. Anton, Howard, Bivens Irl and Davis Stephens (2012). Calculus (10th edn.). John Wiley & Sons, Inc.
3. Denlinger, Charles G. (2011). Elements of Real Analysis, Jones & Bartlett India Pvt. Ltd., Indian Reprint.
4. Ghorpade, Sudhir R. and Limaye, B. V. (2006). A Course in Calculus and Real Analysis. Undergraduate Texts in Mathematics, Springer (SIE). Indian Reprint.

Suggestive Readings

- Bartle, Robert G., & Sherbert, Donald R. (2015). Introduction to Real Analysis (4th ed.). Wiley, Indian Edition.
- Kumar Ajit and Kumaresan S. (2014). A Basic Course in Real Analysis. CRC Press, Taylor & Francis Group, Special Indian Edition.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE– 9: DISCRETE MATHEMATICS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Discrete Mathematics	4	3	0	1	Class XII pass with Mathematics	Algebra and Linear Algebra

Learning Objectives

The primary objective of the course is to:

- Make students embark upon a journey of enlightenment, starting from the abstract concepts in mathematics to practical applications of those concepts in real life.
- Make the students familiar with the notion of partially ordered set and a level up with the study of lattice, Boolean algebra and related concepts.
- Culminate the journey of learning with practical applications using the knowledge attained from the abstract concepts learnt in the course.

Learning Outcomes

This course will enable the students to:

- Understand the notion of partially ordered set, lattice, Boolean algebra with applications.
- Handle the practical aspect of minimization of switching circuits to a great extent with the methods discussed in this course.
- Apply the knowledge of Boolean algebras to logic, set theory and probability theory.

SYLLABUS OF DSC - 9

Unit – 1 **(15 hours)**

Cardinality and Partially Ordered Sets

The cardinality of a set; Definitions, examples and basic properties of partially ordered sets, Order-isomorphisms, Covering relations, Hasse diagrams, Dual of an ordered set, Duality principle, Bottom and top elements, Maximal and minimal elements, Zorn's lemma, Building new ordered sets, Maps between ordered sets.

Unit – 2 **(15 hours)**

Lattices

Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products, Lattice isomorphism; Definitions, examples and properties of modular and distributive lattices; The $M_3 - N_5$ theorem with applications, Complemented lattice, Relatively complemented lattice, Sectionally complemented lattice.

Unit – 3 **(15 hours)**

Boolean Algebras and Applications

Boolean algebras, De Morgan's laws, Boolean homomorphism, Representation theorem, Boolean polynomials, Boolean polynomial functions, Equivalence of Boolean polynomials, Disjunctive normal form and conjunctive normal form of Boolean polynomials; Minimal forms

of Boolean polynomials, Quine-McCluskey method, Karnaugh diagrams, Switching circuits and applications, Applications of Boolean algebras to logic, set theory and probability theory.

Practical (30 hours):

Practical/Lab work to be performed in a computer Lab using any of the Computer Algebra System Software such as Mathematica/MATLAB /Maple/Maxima/Scilab/SageMath etc., for the following problems based on:

1) Expressing relations as ordered pairs and creating relations.
2) Finding whether or not, a given relation is:
   i. Reflexive ii. Antisymmetric iii. Transitive iv. Partial order
3) Finding the following for a given partially ordered set
   i. Covering relations.
   ii. The corresponding Hasse diagram representation.
   iii. Minimal and maximal elements.
4) Finding the following for a subset S of a given partially ordered set P
   i. Whether a given element in P is an upper bound (lower bound) of S or not.
   ii. Set of all upper bounds (lower bounds) of S.
   iii. The least upper bound (greatest lower bound) of S, if it exists.
5) Creating lattices and determining whether or not, a given partially ordered set is a lattice.
6) Finding the following for a given Boolean polynomial function:
   i. Representation of Boolean polynomial function and finding its value when the Boolean variables in it take particular values over the Boolean algebra $\{0,1\}$.
   ii. Display in table form of all possible values of Boolean polynomial function over the Boolean algebra $\{0,1\}$.
7) Finding the following:
   i. Dual of a given Boolean polynomial/expression.
   ii. Whether or not two given Boolean polynomials are equivalent.
   iii. Disjunctive normal form (Conjunctive normal form) from a given Boolean expression.
   iv. Disjunctive normal form (Conjunctive normal form) when the given Boolean polynomial function is expressed by a table of values.
8) Representing a given circuit diagram (expressed using gates) in the form of Boolean expression.
9) Minimizing a given Boolean expression to find minimal expressions.

Essential Readings

1. Davey, B. A., & Priestley, H. A. (2002). Introduction to Lattices and Order (2nd ed.). Cambridge University press, Cambridge.
2. Goodaire, Edgar G., & Parmenter, Michael M. (2006). Discrete Mathematics with Graph Theory (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint.
3. Lidl, Rudolf & Pilz, Gunter. (2004). Applied Abstract Algebra (2nd ed.), Undergraduate Texts in Mathematics. Springer (SIE). Indian Reprint.

Suggested Readings

- Donnellan, Thomas. (1999). Lattice Theory (1st ed.). Khosla Pub. House. Indian Reprint.
- Rosen, Kenneth H. (2019). Discrete Mathematics and its Applications (8th ed.), Indian adaptation by Kamala Krithivasan. McGraw-Hill Education. Indian Reprint 2021.

B.Sc. (Hons) Mathematics, Semester-III, DSE-Courses

DISCIPLINE SPECIFIC ELECTIVE COURSE -1(i): GRAPH THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Graph Theory	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- Problem-solving techniques using various concepts of graph theory.
- Various properties like planarity and chromaticity of graphs.
- Several applications of these concepts in solving practical problems.

Learning Outcomes

This course will enable the students to:

- Learn modelling of real-world problems by graphs.
- Know characteristics of different classes of graphs.
- Learn representation of graphs in terms of matrices.
- Learn algorithms to optimize a solution.
- Understand some properties of graphs and their applications in different practical situations.

SYLLABUS OF DSE - 1(i)

Unit – 1 **(12 hours)**

Graphs, Paths and Circuits

Definition, Examples and basic properties of graphs, Subgraphs, Pseudographs, Complete graphs, Bipartite graphs, Isomorphism of graphs, Paths and circuits, Connected graphs, Eulerian circuits, Hamiltonian cycles, Adjacency matrix, Weighted graph, Travelling salesman problem, Shortest path, Dijkstra's algorithm.

Unit – 2 **(15 hours)**

Applications of Paths and Circuits, Trees

Applications of Path and Circuits: The Chinese Postman Problem, Digraphs, Bellman-Ford Algorithm, Tournaments, Scheduling Problem, Trees, Properties of Trees, Spanning Trees, Minimum Spanning Tree Algorithms.

Unit – 3 **(18 hours)**

Connectivity and Graph Coloring, Planar Graphs

Cut-vertices, Blocks and their Characterization, Connectivity and edge-connectivity, Planar graphs, Euler's formula, Kuratowski theorem, Graph coloring and applications, Matchings, Hall's theorem, Independent sets and covers.

Essential Readings

1. Goodaire, Edgar G., & Parmenter, Michael M. (2006). Discrete Mathematics with Graph Theory (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint.
2. Chartrand, Gary, & Zhang, Ping (2012). A First Course in Graph Theory. Dover Publications.

Suggestive Readings

- Bondy, J. A., and Murty, U.S.R. (2008). Graph Theory. Graduate Texts in Mathematics, Springer.
- Diestel, Reinhard (2017). Graph Theory (5th ed.). Graduate Texts in Mathematics, Springer.
- West, Douglas B. (2001). Introduction to Graph Theory (2nd ed.). Prentice Hall. Indian Reprint.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE– 1(ii): MATHEMATICAL PYTHON

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Python	4	3	0	1	Class XII pass with Mathematics	Basic knowledge of Python

Learning Objectives

The Learning Objectives of this course are as follows:

- To be able to model and solve mathematical problems using Python Programs.
- To experience utility of open-source resources for numerical and symbolic mathematical software systems.

Learning Outcomes

This course will enable the students to use Python:

- For numerical and symbolic computation in mathematical problems from calculus, algebra, and geometry.
- To tabulate and plot diverse graphs of functions and understand tracing of shapes, geometries, and fractals.
- To prepare smart documents with LaTeX interface.

SYLLABUS OF DSE - 1(ii)

Theory

Unit – 1 **(15 hours)**

Drawing Shapes, Graphing and Visualization

Drawing diverse shapes using code and Turtle; Using matplotlib and NumPy for data organization, Structuring and plotting lines, bars, markers, contours and fields, managing subplots and axes; Pyplot and subplots, Animations of decay, Bayes update, Random walk.

Unit – 2 **(18 hours)**

Numerical and Symbolic Solutions of Mathematical Problems

NumPy for scalars and linear algebra on *n*-dimensional arrays; Computing eigenspace, Solving dynamical systems on coupled ordinary differential equations, Functional programming fundamentals using NumPy; Symbolic computation and SymPy: Differentiation and integration of functions, Limits, Solution of ordinary differential equations, Computation of eigenvalues, Solution of expressions at multiple points (lambdify), Simplification of expressions, Factorization, Collecting and canceling terms, Partial fraction decomposition, Trigonometric simplification, Exponential and logarithms, Series expansion and finite differences, Solvers, Recursive equations.

Unit – 3 **(12 hours)**

Document Generation with Python and LaTeX

Pretty printing using SymPy; Pandas API for IO tools: interfacing Python with text/csv, HTML, LaTeX, XML, MSExcel, OpenDocument, and other such formats; Pylatex and writing document files from Python with auto-computed values, Plots and visualizations.

Practical (30 hours): Software labs using IDE such as Spyder and Python Libraries.

- Installation, update, and maintenance of code, troubleshooting.
- Implementation of all methods learned in theory.
- Explore and explain API level integration and working of two problems with standard Python code.

Essential Readings

1. Farrell, Peter (2019). Math Adventures with Python. No Starch Press. ISBN Number: 978-1-59327-867-0.
2. Farrell, Peter and et al. (2020). The Statistics and Calculus with Python Workshop. Packet Publishing Ltd. ISBN: 978-1-80020-976-3.
3. Saha, Amit (2015). Doing Math with Python. No Starch Press. ISBN: 978-1-59327-640-9

Suggested Readings

- Morley, Sam (2022). Applying Math with Python (2nd ed.). Packet Publishing Ltd. ISBN: 978-1-80461-837-0
- Online resources and documentation on the libraries, such as:
  - https://matplotlib.org
  - https://sympy.org
  - https://pandas.pydata.org
  - https://numpy.org
  - https://pypi.org
  - https://patrickwalls.github.io/mathematicalpython/

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE-1(iii): NUMBER THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Number Theory	4	3	1	0	Class XII pass with Mathematics	Algebra

Learning Objectives

The primary objective of this course is to introduce:

- The number theoretic techniques of computations with the flavour of abstraction.
- The Euclidean algorithm, linear Diophantine equations, congruence equations, arithmetic functions and their applications, Fermat's little, Euler's and Wilson's theorems.
- Primitive roots, quadratic residues and nonresidues, the Legendre symbol and the law of Quadratic Reciprocity.
- Introduction to cryptography, public-key cryptosystems and applications.

Learning Outcomes

This course will enable the students to:

- Use modular arithmetic in solving linear and system of linear congruence equations.
- Work with the number theoretic functions, their properties and their use.
- Learn the forms of positive integers that possess primitive roots and the Quadratic Reciprocity Law which deals with the solvability of quadratic congruences.
- Understand the public-key cryptosystems, in particular, RSA.

SYLLABUS OF DSE - 1(iii)

Unit – 1 **(12 hours)**

Linear Diophantine equation and Theory of Congruences

The Euclidean Algorithm and linear Diophantine equation; Least non-negative residues and complete set of residues modulo n; Linear congruences, The Chinese remainder theorem and system of linear congruences in two variables; Fermat's little theorem, Wilson's theorem and its converse, Application to solve quadratic congruence equation modulo odd prime p.

Unit – 2 **(21 hours)**

Number-Theoretic Functions and Primitive Roots

Number-theoretic functions for the sum and number of divisors, Multiplicative function, Möbius inversion formula and its properties; Greatest integer function with an application to the calendar; Euler's Phi-function, Euler's theorem and some properties of the Phi-function; The order of an integer modulo n and primitive roots for primes, Primitive roots of composite numbers n: when n is of the form 2^k, and when n is a product of two coprime numbers.

Unit – 3 **(12 hours)**

Quadratic Reciprocity Law and Public Key Cryptosystems

The quadratic residue and nonresidue of an odd prime and Euler's criterion, The Legendre symbol and its properties, Quadratic Reciprocity law and its application; Introduction to cryptography, Hill's cipher, Public-key cryptography and RSA.

Essential Reading

1. Burton, David M. (2011). Elementary Number Theory (7th ed.). McGraw-Hill Education Pvt. Ltd. Indian Reprint 2017.

Suggestive Readings

- Andrews, George E. (1994). Number Theory. Dover publications, Inc. New York.
- Robbins, Neville (2007). Beginning Number Theory (2nd ed.). Narosa Publishing House Pvt. Ltd. Delhi.
- Rosen, Kenneth H. (2011). Elementary Number Theory and its Applications (6th ed.). Pearson Education. Indian Reprint 2015.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

B.A. (Prog.) with Mathematics as Major

Category-II

DISCIPLINE SPECIFIC CORE COURSE – 3: THEORY OF EQUATIONS AND SYMMETRIES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Theory of Equations and Symmetries	4	3	1	0	Class X pass with Mathematics	Nil

Learning Objectives

The goal of this paper is to acquaint students with certain ideas about:

- Integral roots, rational roots, an upper bound on number of positive or negative roots of a polynomial.
- Finding roots of cubic and quartic equations in special cases using elementary symmetric functions.
- Using Cardon's and Descartes' methods, respectively.

Learning Outcomes

After completion of this paper, the students will be able to:

- Understand the nature of the roots of polynomial equations and their symmetries.
- Solve cubic and quartic polynomial equations with special condition on roots and in general.
- Find symmetric functions in terms of the elementary symmetric polynomials.

SYLLABUS OF DSC-3

Unit – 1 **(18 hours)**

Polynomial Equations and Properties

General properties of polynomials and equations; Fundamental theorem of algebra and its consequences; Theorems on imaginary, integral and rational roots; Descartes' rule of signs for positive and negative roots; Relations between the roots and coefficients of equations, Applications to solution of equations when an additional relation among the roots is given; De Moivre's theorem for rational indices, the nth roots of unity and symmetries of the solutions.

Unit – 2 **(12 hours)**

Cubic and Biquadratic (Quartic) Equations

Transformation of equations (multiplication, reciprocal, increase/diminish in the roots by a given quantity), Removal of terms; Cardon's method of solving cubic and Descartes' method of solving biquadratic equations.

Unit – 3 **(15 hours)**

Symmetric Functions

Elementary symmetric functions and symmetric functions of the roots of an equation; Newton's theorem on sums of the like powers of the roots; Computation of symmetric functions such as $\sum\alpha^2\beta,\ \sum\alpha^2\beta^2,\ \sum\alpha^2\beta\gamma,\ \sum\frac{1}{\alpha^2\beta\gamma},\ \sum\alpha^{-3},\ \sum(\beta+\gamma-\alpha)^2,\ \sum\frac{\alpha^2+\beta\gamma}{\beta+\gamma},\ldots$ of polynomial equations; Transformation of equations by symmetric functions and in general.

Essential Readings

1. Burnside, W.S., & Panton, A.W. (1979). The Theory of Equations (11th ed.). Vol. 1. Dover Publications, Inc. (4th Indian reprint. S. Chand & Co. New Delhi).
2. Dickson, Leonard Eugene (2009). First Course in the Theory of Equations. John Wiley & Sons, Inc. The Project Gutenberg eBook: http://www.gutenberg.org/ebooks/29785

Suggestive Readings

- Prasad, Chandrika (2017). Text Book of Algebra and Theory of Equations. Pothishala Pvt Ltd.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – A-3: DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes

This course will enable the students to:

- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.

- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and system of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS OF DISCIPLINE A-3

Unit – 1 **(15 hours)**

Ordinary Differential Equations

First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**

Explicit Methods of Solving Higher-Order Linear Differential Equations

Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 **(18 hours)**

First and Second Order Partial Differential Equations

Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings

1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings

- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

B.A./B.Sc. (Prog.) with Mathematics as Non-Major

Category-III

DISCIPLINE SPECIFIC CORE COURSE – A-3: DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes

This course will enable the students to:

- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.
- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and System of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS of Discipline A-3

Unit – 1 **(15 hours)**

Ordinary Differential Equations

First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**

Explicit Methods of Solving Higher-Order Linear Differential Equations

Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 **(18 hours)**

First and Second Order Partial Differential Equations

Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings

1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings

- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

B.Sc. (Physical Sciences/Mathematical Sciences) with Mathematics as one of the Core Discipline

Category-III

DISCIPLINE SPECIFIC CORE COURSE – A-3: DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes

This course will enable the students to:

- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.
- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and System of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS of Discipline A-3

Unit – 1 **(15 hours)**

Ordinary Differential Equations

First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**

Explicit Methods of Solving Higher-Order Linear Differential Equations

Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 **(18 hours)**

First and Second Order Partial Differential Equations

Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings

1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings

- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE -1(i): COMBINATORICS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Combinatorics	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to:

- Introduce various techniques of permutations, combinations and inclusion-exclusion.
- Learn basic models of generating functions and recurrence relations in their application to the theory of integer partitions.

Learning Outcomes

After completing the course, student will:

- Enhance the mathematical logical skills by learning different enumeration techniques.
- Be able to apply these techniques in solving problems in other areas of mathematics.
- Be trained to provide reasoning and arguments to justify conclusions.

SYLLABUS OF DSE-1(i)

Unit - 1 **(15 hours)**

Basics of Combinatorics

Basic counting principles, Permutations and Combinations (with and without repetitions), Binomial coefficients, Multinomial coefficients, Counting subsets of size k; Set-partitions, The inclusion-exclusion principle and applications.

Unit - 2 **(18 hours)**

Generating Functions and Recurrence Relations

Generating functions: Generating function models, Calculating coefficients of generating functions, Polynomial expansions, Binomial identity, Exponential generating functions.
Recurrence relations: Recurrence relation models, Divide-and-conquer relations, Solution of linear recurrence relations, Solutions by generating functions.

Unit – 3 **(12 hours)**

Partition

Partition theory of integers: Ordered partition, Unordered partition, Ferrers diagram, Conjugate of partition, Self-conjugate partition, Durfee square, Euler's pentagonal theorem.

Essential Readings

1. Sane, Sharad S. (2013). Combinatorial Techniques. Hindustan Book Agency (India).
2. Tucker, Alan (2012). Applied Combinatorics (6th ed.). John Wiley & Sons, Inc.

Suggested Readings

- Brualdi, Richard A. (2009). Introductory Combinatorics (5th ed.). Pearson Education Inc.
- Cameron, Peter J. (1994). Combinatorics: Topics, Techniques, Algorithms. Cambridge University Press.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE-1(ii): ELEMENTS OF NUMBER THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Elements of Number Theory	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- The Euclidean algorithm and linear Diophantine equations, the Fundamental theorem of arithmetic and some of the open problems of number theory viz. the Goldbach conjecture.
- The modular arithmetic, linear congruence equations, system of linear congruence equations, arithmetic functions and multiplicative functions, e.g., Euler's Phi-function.
- Introduction of the simple encryption and decryption techniques, and the numbers of specific forms viz. Mersenne numbers, Fermat numbers etc.

Learning Outcomes

This course will enable the students to:

- Get familiar with the basic number-theoretic techniques.
- Comprehend some of the open problems in number theory.
- Learn the properties and use of number-theoretic functions and special types of numbers.
- Acquire knowledge about public-key cryptosystems, particularly RSA.

SYLLABUS OF DSE-1(ii)

Unit – 1 **(12 hours)**

Divisibility and Prime Numbers

Revisiting: The division algorithm, divisibility and the greatest common divisor. Euclid's lemma; The Euclidean algorithm, Linear Diophantine equations; The Fundamental theorem of Arithmetic, The sieve of Eratosthenes, Euclid theorem and the Goldbach conjecture; The Fibonacci sequence and its nature.

Unit – 2 **(21 hours)**

Theory of Congruences and Number-Theoretic Functions

Congruence relation and its basic properties, Linear congruences and the Chinese remainder theorem, System of linear congruences in two variables; Fermat's little theorem and its generalization, Wilson's theorem and its converse; Number-theoretic functions for sum and the number of divisors of a positive integer, Multiplicative functions, The greatest integer function; Euler's Phi-function and its properties.

Unit – 3 **(12 hours)**

Public Key Encryption and Numbers of Special Form

Basics of cryptography, Hill's cipher, Public-key cryptosystems and RSA encryption and decryption technique; Introduction to perfect numbers, Mersenne numbers and Fermat numbers.

Essential Reading

1. Burton, David M. (2011). Elementary Number Theory (7th ed.). McGraw-Hill Education Pvt. Ltd. Indian Reprint 2017.

Suggestive Readings

- Jones, G. A., & Jones, J. Mary. (2005). Elementary Number Theory. Springer Undergraduate Mathematics Series (SUMS). Indian Reprint.
- Robbins, Neville (2007). Beginning Number Theory (2nd ed.). Narosa Publishing House Pvt. Ltd. Delhi.
- Rosen, Kenneth H. (2011). Elementary Number Theory and its Applications (6th ed.). Pearson Education. Indian Reprint 2015.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE - DSE-1(iii): THEORY OF EQUATIONS AND SYMMETRIES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Theory of Equations and Symmetries	4	3	1	0	Class X pass with Mathematics	Nil

Learning Objectives

The goal of this paper is to acquaint students with certain ideas about:

- Integral roots, rational roots, an upper bound on number of positive or negative roots of a polynomial.
- Finding roots of cubic and quartic equations in special cases using elementary symmetric functions.
- Using Cardon's and Descartes' methods, respectively.

Learning Outcomes

After completion of this paper, the students will be able to:

- Understand the nature of the roots of polynomial equations and their symmetries.
- Solve cubic and quartic polynomial equations with special condition on roots and in general.
- Find symmetric functions in terms of the elementary symmetric polynomials.

SYLLABUS OF DSE-1(iii)

Unit – 1 **(18 hours)**

Polynomial Equations and Properties

General properties of polynomials and equations; Fundamental theorem of algebra and its consequences; Theorems on imaginary, integral and rational roots; Descartes' rule of signs for positive and negative roots; Relations between the roots and coefficients of equations, Applications to solution of equations when an additional relation among the roots is given; De Moivre's theorem for rational indices, the *n*th roots of unity and symmetries of the solutions.

Unit – 2 **(12 hours)**

Cubic and Biquadratic (Quartic) Equations

Transformation of equations (multiplication, reciprocal, increase/diminish in the roots by a given quantity), Removal of terms; Cardon's method of solving cubic and Descartes' method of solving biquadratic equations.

Unit – 3 **(15 hours)**

Symmetric Functions

Elementary symmetric functions and symmetric functions of the roots of an equation; Newton's theorem on sums of the like powers of the roots; Computation of symmetric functions such as $\sum\alpha^2\beta,\ \sum\alpha^2\beta^2, \sum\alpha^2\beta\gamma, \sum\frac{1}{\alpha^2\beta\gamma}, \sum\alpha^{-3}, \sum(\beta+\gamma-\alpha)^2,\ \sum\frac{\alpha^2+\beta\gamma}{\beta+\gamma},\ldots$ of polynomial equations; Transformation of equations by symmetric functions and in general.

Essential Readings

1. Burnside, W.S., & Panton, A.W. (1979). The Theory of Equations (11th ed.). Vol. 1. Dover Publications, Inc. (4th Indian reprint. S. Chand & Co. New Delhi).
2. Dickson, Leonard Eugene (2009). First Course in the Theory of Equations. John Wiley & Sons, Inc. The Project Gutenberg eBook: http://www.gutenberg.org/ebooks/29785

Suggestive Readings

- Prasad, Chandrika (2017). Text Book of Algebra and Theory of Equations. Pothishala Pvt Ltd.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES OFFERED BY DEPARTMENT OF MATHEMATICS
Category-IV

GENERIC ELECTIVES-GE-3(i): DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes

This course will enable the students to:

- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.
- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and System of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS OF GE-3(i)

Unit – 1 **(15 hours)**

Ordinary Differential Equations

First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**

Explicit Methods of Solving Higher-Order Linear Differential Equations

Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 **(18 hours)**

First and Second Order Partial Differential Equations

Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings

1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings

- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

GENERIC ELECTIVES-GE-3(ii): LATTICES AND NUMBER THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Lattices and Number Theory	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- The concepts of ordered sets, lattices, sublattices and homomorphisms between lattices.
- Distributive lattices along with Boolean algebra and their applications in the real-world.
- Divisibility theory of congruences along with some applications.
- The number-theoretic functions and quadratic reciprocity law.

Learning Outcomes

This course will enable the students to:

- Understand the notion of ordered sets. Learn about lattices, distributive lattices, sublattices and homomorphisms between lattices.
- Become familiar with Boolean algebra, Boolean polynomials, switching circuits and their applications.
- Learn the concept of Karnaugh diagrams and Quinn–McCluskey method which gives an aid to apply truth tables in real-world problems.

- Learn about some fascinating properties of prime numbers, and some of the open problems in number theory, viz., Goldbach conjecture etc.
- Know about modular arithmetic and number-theoretic functions like Euler's Phi-function.
- Find quadratic residues and nonresidues modulo primes using Gauss's Quadratic Reciprocity Law.

SYLLABUS OF GE-3(ii)

Unit – 1 **(21 hours)**

Partially Ordered Sets and Lattices

Definitions, Examples and basic properties of partially ordered sets, Order isomorphism, Hasse Diagram, Maximal and minimal elements, Dual of an ordered set, Duality principle; Statements of Well Ordering Principle and Zorn's Lemma; Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products and homomorphisms, Distributive lattices, Boolean algebras, Boolean polynomials, Minimal forms of Boolean polynomials, Quinn-McCluskey method, Karnaugh diagrams, Switching circuits and applications.

Unit – 2 **(12 hours)**

Divisibility and Theory of Congruences

The division algorithm: GCD, The Euclidean algorithm, Diophantine equation $ax + by = c$ Primes: The Fundamental Theorem of Arithmetic, Infinitude of primes, Twin primes and Goldbach conjecture.

The theory of congruences: Basic properties and applications, Linear congruences and the Chinese Remainder Theorem, Fermat's Little Theorem and Wilson's Theorem.

Unit – 3 **(12 hours)**

Number-Theoretic Functions, Primitive roots and Quadratic Reciprocity Law

Number-Theoretic Functions: Sum and number of divisors, Euler's Phi-function and Euler's generalization of Fermat's Little Theorem.

Primitive roots: The order of an integer modulo n, and primitive roots of an integer.

Quadratic Reciprocity Law: Quadratic residue and nonresidue, Euler's Criterion, The Legendre symbol and its properties and Quadratic Reciprocity Law.

Essential Readings

1. Davey, B A., & Priestley, H. A. (2002). Introduction to Lattices and Order (2nd ed.), Cambridge University Press, Cambridge.
2. Lidl, Rudolf & Pilz, Günter. (1998). Applied Abstract Algebra (2nd ed.), Undergraduate Texts in Mathematics, Springer (SIE), Indian Reprint 2004.
3. Burton, David M. (2012). Elementary Number Theory (7th ed.), Mc-Graw Hill Education Pvt. Ltd. Indian Reprint.

Suggestive Readings

- Rosen, Kenneth H. (2019). Discrete Mathematics and its Applications (8th ed.), Indian adaptation by Kamala Krithivasan. McGraw-Hill Education. Indian Reprint 2021.
- Goodaire, Edgar G., & Parmenter, Michael M. (2006). Discrete Mathematics with Graph Theory (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint 2018.
- Jones, G. A., & Jones, J. Mary. (2005). Elementary Number Theory. Springer Undergraduate Mathematics Series (SUMS). Indian Reprint.

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