

Tutorial letter 101/3/2018

Numerical Methods II **APM3711**

Semesters 1 & 2

Department of Mathematical Sciences

IMPORTANT INFORMATION:

This tutorial letter contains important information about your module.

BARCODE

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1 INTRODUCTION AND WELCOME

Welcome to module APM3711 on Numerical Methods 2. I hope you will find it both interesting and rewarding. This module is offered as a semester module. You will be well on your way to success if you start studying early in the semester and resolve to do the assignments properly. I hope you will enjoy this module, and wish you success with your studies.

1.1 Tutorial matter

The Department of Despatch should supply you with Tutorial Letter 101 at registration and others later. **There is no study guide for this course.**

PLEASE NOTE: Your lecturers cannot help you with missing study material.

Apart from Tutorial Letter 101, you will also receive other tutorial letters during the semester. These tutorial letters will not necessarily be available at the time of registration. Tutorial letters will be despatched to you as soon as they are available or needed.

If you have access to the Internet, you can view the study guide and tutorial letters for the modules for which you are registered on the University's online campus, myUnisa, at <http://my.unisa.ac.za>

Tutorial Letter 101 contains important information about the scheme of work, resources and assignments for this module. I urge you to read it carefully and to keep it at hand when working through the study material, preparing the assignments, preparing for the examination and addressing questions to your lecturers.

In this tutorial letter you will find the assignments as well as instructions on the preparation and submission of the assignments. This tutorial letter also provides information with regard to other resources and where to obtain them. Please study this information carefully.

Certain general and administrative information about this module has also been included. Please study this section of the tutorial letter carefully.

You must read all the tutorial letters you receive during the semester **immediately and carefully**, as they always contain important and, sometimes, urgent information.

2 PURPOSE AND OUTCOMES OF THE MODULE

2.1 Purpose

The purpose of this module is to provide numerical techniques for the approximate solution of initial and boundary-value problems of ordinary differential equations as well as partial differential equations. A minimal prerequisite in differential and integral calculus, differential equation theory, basic analysis and linear algebra are assumed on addition to Numerical Analysis 1. The course focuses on mathematical theory and numerical analysis to ensure that students understand the concepts that underpin each algorithm that we consider. There will also be a significant component of programming in this course. Students can program in any language of their choice, but Matlab, Mathematica or Maple are recommended because they have plotting facility within the program.

2.2 Outcomes

By the end of this module, students should

- 2.2.1 be competent in using Taylor's method of order 2 and higher to approximate the solution of an initial-value problem.
- 2.2.2 be able to use Euler and modified Euler on initial-value problems.
- 2.2.3 demonstrate fluency in Runge-Kutta methods and their error control.
- 2.2.4 must know how multistep methods work and their relative merits.
- 2.2.5 when given a function, they should be able to find a Padé approximation.
- 2.2.6 be able to use the Chebyshev polynomials to find the Chebyshev series and estimate the maximum error of the Chebyshev series over the interval $[-1, 1]$.
- 2.2.7 be able to economise the given power series.
- 2.2.8 be able to apply Gerschgorin's circle theorems in finding eigenvalues and hence the corresponding eigenvectors.
- 2.2.9 be competent in calculating the dominant eigenvalue and the smallest absolute value using the power method.
- 2.2.10 be able to use the shooting method to solve a boundary-value problem both theoretically and numerically.
- 2.2.11 be competent in solving characteristic-value problem using finite difference method.
- 2.2.12 be able to model a steady-state heat by Laplace's equation and approximate it by the 5-point difference formula and hence obtain the solution numerically.
- 2.2.13 be able to apply the iteration formula for S.O.R. on Laplace equation and hence find numerical solution.
- 2.2.14 have a thorough grasp of the alternating-direction-implicit method (ADI) for solving Laplace/Poisson equation and do this numerically.

3 LECTURER AND CONTACT DETAILS

3.1 Lecturer

The lecturer responsible for this module is:

Dr GM Moremedi
Theo van Wyk Building, room 6-121
E-mail address: moremgm@unisa.ac.za
Telephone number: 012 429 6601 (RSA) +27 12 429 6601 (International)

All queries that are not of a purely administrative nature but are about the content of this module should be directed to me. Email is the preferred form of communication to use. If you phone me please have your study material with you when you contact me. If you cannot get hold of me, leave a message with the Departmental Secretary. Please clearly state your name, time of call and how I can get back to you.

You are always welcome to come and discuss your work with me, but **please make an appointment before coming to see me**. Please come to these appointments well prepared with specific questions that indicate your own efforts to have understood the basic concepts involved.

You are also free to write to me about any of the difficulties you encounter with your work for this module. If these difficulties concern exercises which you are unable to solve, you must send your attempts so I can see where you are going wrong, or what concepts you do not understand. Mail should be sent to:

Dr GM Moremedi
Department of Mathematical Sciences
PO Box 392
UNISA
0003

PLEASE NOTE: Letters to lecturers may not be enclosed with or inserted into assignments.

3.2 Department

Fax number: 012 429 6064 (RSA) +27 12 429 6064 (International)
Departmental Secretary: 012 429 6202 (RSA) +27 12 429 6202 (International)

3.3 University (contact details)

If you need to contact the University about matters not related to the content of this module, please consult the publication *Study @ Unisa* that you received with your study material. This brochure contains information on how to contact the University (e.g. to whom you can write for different queries, important telephone and fax numbers, addresses and details of the times certain facilities are open).

Always have your student number at hand when you contact the University.

4 MODULE RELATED RESOURCES

4.1 Prescribed book

The prescribed textbooks are

Numerical Analysis	Applied Numerical Analysis
Richard L Burden & J. Douglas Faires	Gerald Wheatley
Brookes/Cole	Pearson
Nineth Edition	Seventh Edition, 2004
ISBN-13: 978-0-538-73564-3	
ISBN-10: 0-538-73564-3	

Please refer to the list of official booksellers and their addresses in the *Study @ Unisa* brochure. Prescribed books can be obtained from the University's official booksellers. If you have difficulty in locating your book(s) at these booksellers, please contact the Prescribed Book Section at Tel: 012 429-4152 or e-mail vospresc@unisa.ac.za.

4.2 Recommended books

There are no recommended books for this module. You may use any book which covers the outcomes listed in this Tutorial Letter.

4.3 e-Reserves

There are no e-Reserves for this module. You may use the internet for concepts that are covered in the outcomes.

4.4 Library services and resources information

For brief information, go to www.unisa.ac.za/brochures/studies

For detailed information, go to <http://www.unisa.ac.za/library>. For research support and services of personal librarians, click on "Research support".

The library has compiled a number of library guides:

- finding recommended reading in the print collection and e-reserves
– <http://libguides.unisa.ac.za/request/undergrad>
- requesting material
– <http://libguides.unisa.ac.za/request/request>
- postgraduate information services
– <http://libguides.unisa.ac.za/request/postgrad>
- finding, obtaining and using library resources and tools to assist in doing research
– http://libguides.unisa.ac.za/Research_Skills
- how to contact the library/finding us on social media/frequently asked questions
– <http://libguides.unisa.ac.za/ask>

5 STUDENT SUPPORT SERVICES FOR THE MODULE

For information on the various student support systems and services available at Unisa (e.g. student counselling, language support), please consult the publication *Study @ Unisa* that you received with your study material.

5.1 Study groups

It is advisable to have contact with fellow students. One way to do this is to form study groups. The addresses of students in your area may be obtained from the following department:

Directorate: Student Administration and Registration
PO Box 392
UNISA
0003

myUnisa

If you have access to a computer that is linked to the internet, you can quickly access resources and information at the University. The *myUnisa* learning management system is Unisa's online campus that will help you to communicate with your lecturers, with other students and with the administrative departments of Unisa all through the computer and the internet.

To go to the *myUnisa* website, start at the main Unisa website, www.unisa.ac.za, and then click on the "*myUnisa*" link below the orange tab labelled "Current students". This should take you to the myUnisa website. You can also go there directly by typing my.unisa.ac.za in the address bar of your browser.

Please consult the publication *Study @ Unisa* which you received with your study material for more information on *myUnisa*.

6 MODULE SPECIFIC STUDY PLAN

Study plan	Semester 1	Semester 2
Outcomes 2.2.1 to 2.2.7 to be achieved by	12 March	22 August
Outcomes 2.2.8 to 2.2.14 to be achieved by	10 April	12 September
Work through concepts not well grasped	20 April	30 September
Revision	30 April	15 October

7 MODULE PRACTICAL WORK AND WORK INTEGRATED LEARNING

There are no practicals for this module.

8 ASSESSMENT

8.1 Assessment plan

In each semester there are two assignments for APM3711. Both assignments are written assignments. The solutions to both 01 and 02 will be sent to ALL registered students after the due date. The questions for the assignments for both semesters are given in 8.4. Both assignments count towards your semester mark. Please make sure that you **answer the questions for the semester for which you are registered**. When marking the assignments, constructive comments will be made on your work, which will then be returned to you. The assignments and the comments on these assignments constitute an important part of your learning and should help you to be better prepared for the next assignment and the examination. Please do not wait until you receive Assignment 01 back before you start working on Assignment 02.

To be admitted to the examination you need to submit the first assignment before the compulsory date.

Your semester mark for APM3711 counts 10% and your exam mark 90% of your final mark. Both assignments count 50% towards the year mark.

8.2 General assignment numbers

The assignments are numbered as 01 and 02 for each semester.

8.2.1 Unique assignment numbers

Please note that each assignment also has their own unique assignment number which has to be written on the cover of your assignment upon submission.

8.2.2 Due dates of assignments

The due dates for the submission of the assignments in 2012 are:

Assignment number	Semester 1	Semester 2
01	23 March 2018	27 August 2018
02	20 April 2018	21 September 2018

8.3 Submission of assignments

You may submit your assignments either by post or electronically via *myUnisa*. Assignments may **not** be submitted by fax or e-mail. For detailed information on assignments, please refer to the *Study @ Unisa* brochure, which you received with your study package. Assignments should be sent to

The Registrar
P.O. Box 392
UNISA
0003

To submit an assignment via myUnisa:

- Go to myUnisa.
- Log in with your student number and password.
- Select the module.
- Click on assignments in the menu on the left-hand side of the screen.
- Click on the assignment number you wish to submit.
- Follow the instructions.

PLEASE NOTE: Although students may work together when preparing assignments, each student must write and submit his or her own individual assignment. In other words, you must submit your own calculations in your own words. It is unacceptable for students to submit identical assignments on the basis that they worked together. That is copying (a form of plagiarism) and none of these assignments will be marked. Furthermore, you may be penalised or subjected to disciplinary proceedings by the University.

8.4 Assignments

ONLY FOR SEMESTER 1 STUDENTS
ASSIGNMENT 01

FIXED CLOSING DATE: 23 MARCH 2018
Unique Number: 635303

Question 1

Use the simple Euler method for the differential equation.

$$\frac{dy}{dx} = \frac{x}{y}, \quad y(0) = 1,$$

with

(a) $h = 0.2$,

(b) $h = 0.1$

to get $y(1)$. Compare your numerical solution with the analytical solution,

$$y^2 = 1 + x^2.$$

Question 2

Solve the differential equation given below by means of the Taylor-series expansion to get the value of y at $x = 1.1$. Use terms up to x^6 and $\Delta x = 0.1$.

$$\begin{aligned} \frac{d^2y}{dx^2} &= xy^2 - 2yy' + x^3 + 4, \\ y(1) &= 1, \quad y'(1) = 2. \end{aligned}$$

Question 3

Consider the system of coupled second-order differential equations

$$\begin{aligned}u'' - (t + 1)(u')^2 + 2uv - u^3 &= \cos t \\2v'' + (\sin t)u'v' - 6u &= 2t + 3\end{aligned}$$

with initial conditions

$$u(0) = 1, \quad u'(0) = 2, \quad v(0) = 3, \quad v'(0) = 4.$$

Use the second-order Runge-Kutta method with $h = 0.2$ and $a = 2/3$, $b = 1/3$, $\alpha = \beta = 3/2$, to find u , u' , v and v' at $t = 0.2$.

Question 4

Consider the boundary value problem

$$\frac{d^2y}{dx^2} + 2xy = 2, \quad 0 \leq x \leq 2.$$

Set up the set of equations to solve this problem by the method of finite differences when $h = \Delta x = \frac{1}{2}$ is used, in each of the following cases of boundary conditions. (You do not have to solve the equations.)

(a) $y(0) = 5,$
 $y(2) = 10.$

(b) $y'(0) = 2,$
 $y(2) = 0.$

Question 5

The predictor and corrector formulas of the Adam-Moulton method are:

$$y_{n+1} = y_n + \frac{h}{24} (55f_n - 59f_{n-1} + 37f_{n-2} - 9f_{n-3}) + \frac{251}{720}h^5y^{(5)}(\zeta_1)$$

$$y_{n+1} = y_n + \frac{h}{24} (9f_{n+1} + 19f_n - 5f_{n-1} + f_{n-2}) - \frac{19}{720}h^5y^{(5)}(\zeta_2).$$

Apply the Adams-Moulton method to calculate the approximate value of $y(0.8)$ and $y(1.0)$ from the differential equation

$$y' = t + y$$

and the starting values

t	y(t)
0.0	0.95
0.2	0.68
0.4	0.55
0.6	0.30

Use 3 decimal digits with rounding at each step.

Question 6

(a) Given the truncated power series

$$p(x) = 1 - x + \frac{x^2}{2} - \frac{x^3}{3} + \frac{x^4}{4} - \frac{x^5}{5}$$

and the Chebyshev polynomial

$$T_5(x) = 16x^5 - 20x^3 + 5x.$$

- (i) What is the purpose of economizing a power series?
- (ii) Economize the power series $p(x)$.
- (iii) What is the maximum value of $|T_5(x)|$ in the interval $[-1; 1]$?
- (iv) If $q(x)$ denotes the economized series obtained in (ii), what is the maximum value of $|p(x) - q(x)|$ in the interval $[-1; 1]$?

(b) We want to find a Padé approximation $R_6(x)$, with denominator of degree 3, to the function

$$e^{x^2} = 1 + x^2 + \frac{x^4}{2} + \frac{x^6}{6} + \dots$$

- (i) Why is it often preferred to approximate a function by a rational function rather than by a polynomial?
- (ii) Write down $R_6(x)$ with coefficients a_i and b_i .
- (iii) Set up the equations to find the coefficients, but do NOT solve the system.

ONLY FOR SEMESTER 1 STUDENTS
ASSIGNMENT 02

FIXED CLOSING DATE: 20 APRIL 2018
Unique Number: 894108

Question 1

Consider the eigenvalue problem $Ax = \lambda x$ with

$$A = \begin{bmatrix} -6 & 0 & 6 \\ 4 & 9 & 2 \\ -3 & 0 & 5 \end{bmatrix} \quad \text{and} \quad A^{-1} = \begin{bmatrix} -\frac{5}{12} & 0 & \frac{1}{2} \\ \frac{13}{54} & \frac{1}{9} & -\frac{1}{3} \\ -\frac{1}{4} & 0 & \frac{1}{2} \end{bmatrix}.$$

- (a) the dominant eigenvalue and the associated eigenvector,
- (b) the eigenvalue with the smallest absolute value and the associated eigenvector,
- (c) the remaining eigenvalue and the associated eigenvector.

In all cases, start with the vector $(1, 1, 1)$ and iterate three times. Use at least 4 decimal digits with rounding.

Question 2

Consider the characteristic-value problem

$$y'' - x^2 y' + ky = 0, \quad y(0) = y(1) = 0.$$

Taking $h = 0.2$, derive an eigenvalue problem for determining the non-zero values of k for which the differential equation has non-trivial solutions. (Do not solve the eigenvalue problem.)

Question 3

Solve the boundary-value problem

$$\begin{aligned} y'' + (y')^2 - 9xy &= -9x^3 + 36x^2 + 6x - 6, \\ y(1) &= -2, \quad y(2) = -4 \end{aligned}$$

by using the **shooting method**. Use the modified Euler method (with only one correction at each step), and take $h = 0.2$. Start with an initial slope of $y'(1) = -2.99$ as a first attempt and $y'(1) = -3.01$ as a second attempt. Then interpolate. Continue until the solutions corresponding to two consecutive estimates of $y'(1)$ agree in at least 2 decimal places. Compare the result with the analytical solution $y = x^3 - 3x^2$.

Question 4

Consider the partial differential equation

$$yu - 2\nabla^2 u = 12, \quad 0 < x < 4, \quad 0 < y < 3$$

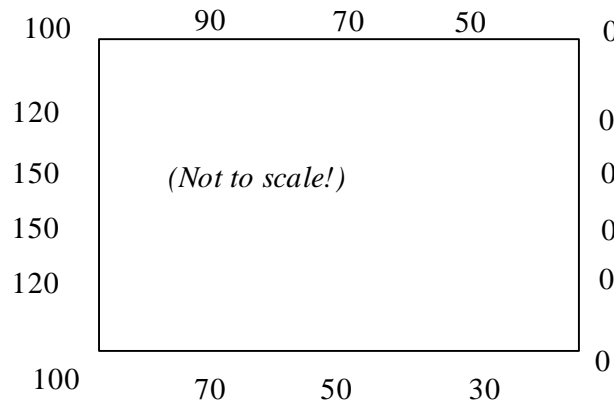
with boundary conditions

$$\begin{aligned} x &= 0 \text{ and } x = 4 : u = 60 \\ y &= 0 \text{ and } y = 3 : \frac{\partial u}{\partial y} = 5. \end{aligned}$$

- Taking $h = 1$, sketch the region and the grid points. Use symmetry to minimize the number of unknowns u_i that have to be calculated and indicate the u_i in the sketch.
- Use the 5-point difference formula for the Laplace operator to derive a system of equations for the u_i .

Question 5

We have a plate of 12×15 cm and the temperatures on the edges are held as shown in the sketch below. Take $\Delta x = \Delta y = 3$ cm and use the **S.O.R. method** (successive overrelaxation method) to find the temperatures at all the gridpoints. First calculate the optimal value of ω and then use this value in the algorithm. Start with all grid values equal to the arithmetic average of the given boundary values.



Question 6

Solve the problem in question 5 by using the **A.D.I method** (alternating-direction-implicit method) without overrelaxation.

ONLY FOR SEMESTER 2 STUDENTS
ASSIGNMENT 01

FIXED CLOSING DATE: 27 AUGUST 2018
Unique Number: 634903

Question 1

Solve the given differential equation below by means of the Taylor-series expansion to get the value of y at $x = 0.1$. Use terms up to x^6 .

$$\frac{dy}{dx} = 3x + 2y + xy, \quad y(0) = -1.$$

Question 2

Consider the differential equation

$$y' = -xy^2, \quad y(0) = 2.$$

Apply the **modified Euler method** to solve the equation up to $x = 1$ in steps of $h = 0.2$. (Do not recompute.) Compare with the analytical solution

$$y = \frac{2}{x^2 + 1}.$$

Question 3

Solve the pair of simultaneous differential equations

$$\frac{dx}{dt} = x^2 + t, \quad x(0) = 2,$$

$$\frac{dy}{dt} = xy - 2, \quad y(0) = 1$$

by the simple Euler method with $\Delta t = 0.1$ to get $x(1)$ and $y(1)$.

Question 4

Consider the differential equation

$$y' = y - x^2 \quad y(0) = 1$$

and starting values

$$y(0.2) = 1.2186, \quad y(0.4) = 1.4682, \quad y(0.6) = 1.7379.$$

Use the fourth-order **Adams–Moulton** predictor–corrector method with $h = 0.2$ to solve the equation up to $x = 1.2$.

Compare with the analytical solution,

$$y = x^2 + 2x + 2 - e^x.$$

Question 5

Consider the boundary value problem

$$\frac{d^2y}{dx^2} + 2xy = 2, \quad 0 \leq x \leq 2.$$

Set up the set of equations to solve this problem by the method of finite differences when $h = \Delta x = \frac{1}{2}$ is used, in each of the following cases of boundary conditions. (You do not have to solve the equations.)

- (a) $y(0) = 5,$
 $y(2) = 10.$
- (b) $y'(0) = 2,$
 $y(2) = 0.$

QUESTION 6

- (a) The first few Chebyshev polynomials are

$$\begin{aligned} T_0 &= 1 \\ T_1 &= x \\ T_2 &= 2x^2 - 1 \\ T_3(x) &= 4x^3 - 3x \\ T_4(x) &= 8x^4 - 8x^2 + 1. \end{aligned}$$

- (i) What is the purpose of economizing a power series?
- (ii) Find the Chebyshev series for the function $p(x)$ with the Maclaurin series

$$p(x) = 1 - \frac{x}{2} + \frac{x^2}{4} - \frac{x^3}{6} + \frac{x^4}{8} - \dots$$

- (iii) Find an estimate for the error made if the Chebyshev series for $p(x)$ is truncated to include terms up to T_3 .

- (b) Find the Padé approximation $R_5(x)$, with denominator of degree 2, to the function

$$f(x) = 1 + x^2 - x^4.$$

ONLY FOR SEMESTER 2 STUDENTS
ASSIGNMENT 02

FIXED CLOSING DATE: 21 SEPTEMBER 2018
Unique Number: 736822

QUESTION 1

- (a) Define what is meant by the eigenvalues and eigenvectors of a matrix A .

If the matrix A is

$$A = \begin{bmatrix} -4 & 14 & 0 \\ -5 & 13 & 0 \\ -1 & 0 & 2 \end{bmatrix},$$

- (b) find the characteristic polynomial,
- (c) find the eigenvalues and eigenvector.
- (d) Start with the approximate eigenvector (1,1,1) and use the power method to estimate the dominant eigenvalue by iterating 4 times.
- (e) Use the **power method** to find the smallest absolute eigenvalue of A .

QUESTION 2

Consider the characteristic-value problem

$$y'' - 3y' + 2k^2y = 0, \quad y(0) = 0, \quad y(1) = 0.$$

Using the method of finite differences, with

- (a) $h = \frac{1}{2}$,
- (b) $h = \frac{1}{3}$,
- (c) $h = \frac{1}{4}$,

derive an eigenvalue problem for determining the non-zero values of k for which the differential equation has non-trivial solutions.

Question 3

Solve the boundary-value problem

$$\begin{aligned} y'' + (y')^2 - 9xy &= -9x^3 + 36x^2 + 6x - 6, \\ y(1) &= -2, \quad y(2) = -4 \end{aligned}$$

by using the **shooting method**. Use the modified Euler method (with only one correction at each step), and take $h = 0.2$. Start with an initial slope of $y'(1) = -2.99$ as a first attempt and $y'(1) = -3.01$ as a second attempt. Then interpolate. Continue until the solutions corresponding to two consecutive estimates of $y'(1)$ agree in at least 2 decimal places. Compare the result with the analytical solution $y = x^3 - 3x^2$.

QUESTION 4

Solve $\nabla^2 u = f(x, y)$ on the square region bounded by

$$x = 0, \quad x = 1, \quad y = 0, \quad y = 1,$$

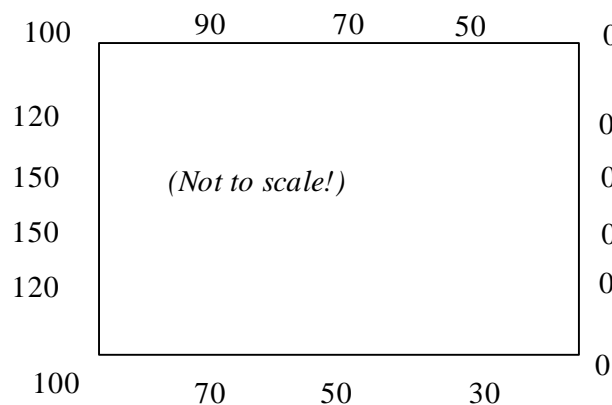
with $f(x, y) = xy$, and boundary conditions

$$\begin{aligned} u &= 6 \quad \text{when } x = 0, \\ u &= 0 \quad \text{when } y = 0, \\ u &= 4 \quad \text{when } x = 1, \\ \frac{\partial u}{\partial y} &= 0 \quad \text{when } y = 1. \end{aligned}$$

Use $h = \frac{1}{3}$.

QUESTION 5

We have a plate of 12×9 cm and the temperatures on the edges are held as shown in the sketch. Take $\Delta x = \Delta y = 3$ cm and use the **S.O.R. method** (successive overrelaxation method) to find the temperatures at all the grid-points. First calculate the optimal value of ω and then use this value in the algorithm.



QUESTION 6

Solve the problem in Question 5 by using the **A.D.I. method** (alternating–direction–implicit method) with $\Delta x = \Delta y = 3$ cm and $\rho = 1.0$.

9 OTHER ASSESSMENT METHODS

There are no other assessment methods for this module.

10 EXAMINATIONS

10.1 Examination admission

To be admitted to the examination you must submit the compulsory assignment, i.e. Assignment 01, by the due date (23 March 2018 for Semester 1, and 27 August 2018 for Semester 2).

10.2 Examination period

This module is offered in a semester period of fifteen weeks. This means that if you are registered for the first semester, you will write the examination in May/June 2018 and the supplementary examination will be written in October/November 2018. If you are registered for the second semester you will write the examination in October/November 2018 and the supplementary examination will be written in May/June 2019.

During the semester, the Examination Section will provide you with information regarding the examination in general, examination venues, examination dates and examination times.

10.3 Examination paper

The textbook forms the basis of this course. The study outcomes are listed under 2.2 of this tutorial letter. The examination will be a single written paper of two hours duration.

Refer to the *Study @ Unisa* brochure for general examination guidelines and examination preparation guidelines.

You are allowed to use a calculator in the exam.

11 FREQUENTLY ASKED QUESTIONS

For any other study information see the brochure *Study @ Unisa*.

12 SOURCES CONSULTED

No other books except the textbooks were used in this module.

13 CONCLUSION

Read your tutorial letter carefully, follow the study guide reference and outcomes and do as many exercises as possible.