# TEACHING INSTRUCTIONAL DESIGN (BRP)

## COURSE

## CONTROL SYSTEM

**by**

**Dr. Arief Sudarmaji**

**Undergraduate Program in Physics**
**Faculty of Mathematics and Natural Sciences**
**Universitas Indonesia**
**Depok**
**November 2020**

# UNIVERSITAS INDONESIA
# FACULTY OF MATHEMATICS AND NATURAL SCIENCES
# PHYSICS UNDERGRADUATE STUDY PROGRAM

**TEACHING INSTRUCTIONAL DESIGN**

| **Course Name** | Control System | **Credit(s)** | **Prerequisite course(s)** | **Requisite for course(s)** | **Integration Between Other Courses** |
|---|---|---|---|---|---|
| **Course Code** | SCPH603714 | 2 | Electronics 1 and Electronics 2 | - | Laboratory Work of Control System |
| **Relation to Curriculum** | - | | | | |
| **Semester** | 6 | | | | |
| **Lecturer(s)** | Dr. Arief Sudarmaji | | | | |
| **Course Description** | Giving the basic concepts about control systems such as feedback and control systems, Laplace transformation, linear transfer function systems, linearization of unilinear systems, modelling mathematical systems, mechanical and electrical systems, block diagram modelling, graphical signal flow modelling, state variable models, error signal analysis, sensitivity of feedback control system towards the variety of parameters in the control system, signal disturbance in a feedback control system, controlling the transient response of a system, steady state errors, second order system, effects of third pole and zero's in a second order system, work index of control systems, simplification of linear systems, analyzation of loop systems (open and closed loop), testing the stability of control systems using characteristic functions and the Ruth Hurwitz method, control system design: root locus concept, parameter design of control system using the root locus, determining the parameters of PID using trial and error methods, identifying the process of a stable open loop system, determining the parameters of a PID with the Direct Synthesis, Inter Model Control, System Index, Ziegler Nichols, Cohen Coon and Reactive Curve methods, | | | | |

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| | analyzing the frequency response using the Bode and Nyquist plot, designing PI, PID, Lead, Lag, and Lead Lag systems, and finally, designing feedback systems with state variables. |
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| **Program Learning Outcome (PLO)** | |
| PLO | Applying the concepts of Control Systems |
| PLO | Formulating problems and solving Physics and its application, as well as interdisciplinary problems related to science and mathematics clusters critically, creatively, and innovatively. |
| PLO | Solving simple scientific problems and presenting them orally and in writing |
| **Course Learning Outcome (CLO)** | |
| CLO | Students are able to understand problems and apply interfacing and programming methods in embedded systems effectively and efficiently. (C3) (ELO 3, 5, 6, 7) |
| **Sub-CLO** | |
| Sub-CLO 1 | Explaining the basic concepts of Control Systems and sample configurations of control systems, analyzing control systems and target criteria's of designing a control system as well as the process that has to be followed while designing one (C2 and C3) |
| Sub-CLO 2 | Explaining the basic concepts of the Laplace transform, modeling in electrical, mechanic and electromechanics systems, and linearization of non-linear systems (C2 and C3) |

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| Sub-CLO 3 | Explaining the basic concepts pole and zeroes of a transfer function to determine the response time from a control system, explaining quantitively the response of a first order system, explaining the normal response of a second order system, and determining the damping ratio, natural frequency, settling time, peak time, percent overshoot, and rise time of a second order system (C2 and C3) |
| Sub-CLO 4 | Explaining the basic concepts of steady-state error and its specifications, determining the steady state error as a result of an interrupt, determining the sensitivity of a steady-state error as a result of a change in the parameters of the control system, and explaining the Routh Hurwitz method to determine the stability in a control system (C2 and C3) |
| Sub-CLO 5 | Explaining the basic concepts of the root locus technique, the characteristics of the root locus technique, how to plot using the root locus, and using the root locus to determine the main parameters for the components of a control system (C2 and C3) |
| Sub-CLO 6 | Explaining the basic concepts of the root locus technique to design a control system or a compensator for increasing the transient performance and steady state error of a system, and realizing the compensator physically (C2 and C3) |
| Sub-CLO 7 | Explaining the basic concepts of the frequency response in a control system, plotting the frequency response, Nyquist diagram sketch and using it to determine the stability of a control system, define and draw a Bode plot, determining the gain margin, and determining the phase margin (C2 and C3) |
| Sub-CLO 8 | Explaining the basic concepts of setting the gain to fulfill the criteria needed for the transient response, to design a control system or a compensator to increase the transient performance and the steady state error performance with the frequency response method (C2 and C3) |

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| Sub-CLO 9 | Explaining the basic concepts on mathematical models used to represent the linear time invariant state system, models in the electric and mechanic state space, changing a transfer function to a state space and backwards, as well as linearization in a state space system (C2 and C3) |
| Sub-CLO 10 | Explaining the basic concepts of designing a state feedback controller with a determined position for the pole, determining if a system is controllable and observable, designing a state feedback controller to fulfill the specifications of the transient response and steady state error performance (C2 and C3) |
| Sub-CLO 11 | Explaining the basic concepts of modelling the digital computer in a feedback system, the z-transform and the inverse z-transform, determining the transfer function for sampled data's, determining the stability of a sampled-data system and determining if the sampling rates to stabilize the system, and designing a digital control system to fulfill the criterions of a steady state error and transient response (C2 and C3) |
| Sub-CLO 12 | Explaining the basic concepts of designing and tuning a PID controller using the Direct Synthesis, IMC, Ziegler Nichols, Cohen Coon and the Reactive Curve method (C2 and C3) |
| Sub-CLO 13 | Designing an embedded system in the form of a project (C3) |
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| **Study Materials** | • Control Systems<br>• Laplace Transformation<br>• Linearization of Unlinear Systems<br>• Modelling Mathematical Systems<br>• Mechanical and Electrical Systems<br>• Block Diagram Modelling<br>• Graphical Signal Flow Modelling<br>• Graphical Signal Flow Modelling<br>• State Variable Models<br>• Error Signal Analysis<br>• Sensitivity of feedback control system towards the variety of parameters in the control system<br>• Siganl disturbance in a Feedback Control System |

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| | • Controlling the transient response of a system<br>• Steady State Errors<br>• Second order system<br>• Effects of third pole and zero’s in a second order system<br>• Work index of control systems<br>• Simplification of lienar systems<br>• Analyzation of loop systems (open and closed loop)<br>• Testing the stability of control systems using characteristics functions and the Ruth Hurwitz Method<br>• Control system Design<br>• Root locus concepts<br>• Parameter design of control system using the root locus<br>• Determining the parameters of PID using trial and error methods, Direct Synthesis, Inter Model Control, System Index, Ziegler Nichols, Cohen Coon and the Reaction Curve Method<br>• Analyzing frequency response using the Bode and Nyquist plot<br>• Designining PI, PID, Lead, Lag, and Leag Lag systems<br>• Designing feedback systems with state variables |
| Reading List | ▪ N.S. Nise, M.A, *Control Systems Engineering*, 7th edition, Wiley, 2015.<br>▪ R. C. Dorf and R.H. Bishop, *Modern Control System*, 12th edition, Prentice Hall, 2011<br>▪ D.E. Seborg, T.F. Edgar, D.A. Mellichamp, and F.J. Doyle, *Process Dynamics and Control*, 4th edition, Wiley, 2017. |

**Teaching Plan**

| Week | Sub-CLO | Study Materials [with reference] | Teaching Method [with est. time] | Learning Experiences (*O-E-F) | Sub-CLO Achievement Indicator | | Sub-CLO Weight on Course (%) |
|---|---|---|---|---|---|---|---|
| | | | | | General | Specific | |
| 1 | 1 | • Introduction to Control Systems<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: | Able to explain the basic concepts of:<br>a) Control Systems and sample configurations of control systems<br>b) Analyzing control systems and target criteria's of designing a control system<br>c) The process that has to be | Students are able to analyze and give feedback towards the concept of:<br>a) Control Systems and sample configurations of control systems<br>b) Analyzing control systems and target criteria's of | 7% |

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| | | | | Question and answer with the lecturer (40%) | followed while designing one | designing a control system<br>c) The process that has to be followed while designing one | |
| 2 | 2 | • Modelling in the frequency domain<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | Able to explain the basic concepts of:<br>a) Laplace transform<br>b) Modeling in electrical, mechanic and electromechanics systems<br>c) Linearization of non-linear systems Assembly Programming | Students are able to analyze and give feedback towards the concept of:<br>a) Laplace transform<br>b) Modeling in electrical, mechanic and electromechanics systems<br>c) Linearization of non-linear systems Assembly Programming | 7% |
| 3 | 3 | • Characteristics and performance of a closed control system (1)<br><br>[Reference] | Lecturing classes and individual tasks | Orientation: Introduction to this week's topic (50%) | Able to explain the basic concepts of:<br>a) Pole and zeroes of a transfer function to | Students are able to analyze and give feedback towards the concept of:<br>a) Pole and zeroes of a transfer | 7% |

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|---|---|---|---|---|---|---|---|
| | | 1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | [Estimated time]<br>100 minutes | Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | determine the response time from a control system<br>b) Explaining quantitively the response of a first order system<br>c) Explaining the normal response of a second order system<br>d) Determining the damping ratio, natural frequency, settling time, peak time, percent overshoot, and rise time of a second order system | function to determine the response time from a control system<br>b) Explaining quantitively the response of a first order system<br>c) Explaining the normal response of a second order system<br>a) Determining the damping ratio, natural frequency, settling time, peak time, percent overshoot, and rise time of a second order system | |
| 4 | 4 | • Characteristics and performance of a closed control system (2) | Lecturing classes and | Orientation: | Able to explain the basic concepts of: | Students are able to analyze and give feedback towards the concept of: | 7% |

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|---|---|---|---|---|---|---|---|
| | | [Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | individual tasks<br><br>[Estimated time]<br>100 minutes | Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | a) Steady-state errors and its specifications<br>b) Determining the steady state error as a result of an interrupt<br>c) Determining the sensitivity of a steady-state error as a result of a change in the parameters of the control system<br>d) Routh Hurwitz method to determine the stability in a control system | a) Steady-state errors and its specifications<br>b) Determining the steady state error as a result of an interrupt<br>c) Determining the sensitivity of a steady-state error as a result of a change in the parameters of the control system<br>a) Routh Hurwitz method to determine the stability in a control system | |
| 5 | 5 | • Root Locus Method<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: | Able to explain the basic concepts of:<br>a) The root locus technique<br>b) The characteristics of the root locus technique | Students are able to analyze and give feedback towards the concept of:<br>a) The root locus technique<br>b) The characteristics of | 7% |

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| | | | | Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | c) How to plot using the root locus<br>d) Using the root locus to determine the main parameters for the components of a control system | the root locus technique<br>c) How to plot using the root locus<br>d) Using the root locus to determine the main parameters for the components of a control system | |
| 6 | 6 | • Designing a control system using the root locus method<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer | Able to explain the basic concepts of:<br>a) The root locus technique to design a control system or a compensator for increasing the transient performance and steady state error of a system | Students are able to analyze and give feedback towards the concept of:<br>a) The root locus technique to design a control system or a compensator for increasing the transient performance and steady state error of a system | 7% |

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| | | | | with the lecturer (40%) | b) Realizing the compensator physically | b) Realizing the compensator physically | |
| 7 | 7 | • Frequency Response Method<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | Able to explain the basic concepts of:<br>a) The frequency response in a control system<br>b) Plotting the frequency response<br>c) Nyquist diagram sketch and using it to determine the stability of a control system<br>d) define and draw a Bode plot, determining the gain margin, and determining the phase margin | Students are able to analyze and give feedback towards the concept of:<br>a) The frequency response in a control system<br>b) Plotting the frequency response<br>c) Nyquist diagram sketch and using it to determine the stability of a control system<br>d) define and draw a Bode plot, determining the gain margin, and determining the phase margin | 7% |
| 8 | **Mid Term Exam** | | | | | | |
| 9 | 8 | • Designing a control system using the frequency response method | Lecturing classes and | Orientation: | Able to explain the basic concepts of: | Students are able to analyze and give | 7% |

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|---|---|---|---|---|---|---|---|
| | | [Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | individual tasks<br><br>[Estimated time]<br>100 minutes | Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | a) Setting the gain to fulfill the criteria needed for the transient response<br>b) Designing a control system or a compensator to increase the transient performance and the steady state error performance with the frequency response method | feedback towards the concept of:<br>a) Setting the gain to fulfill the criteria needed for the transient response<br>b) Designing a control system or a compensator to increase the transient performance and the steady state error performance with the frequency response method | |
| 10 | 9 | • Modelling in the time domain<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture | Able to explain the basic concepts of:<br>a) Mathematical models used to represent the linear time invariant state system<br>b) Models in the electric and | Students are able to analyze and give feedback towards the concept of:<br>a) Mathematical models used to represent the linear time invariant state system | 7% |

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| | | | | (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | mechanic state space<br>c) Changing a transfer function to a state space and backwards<br>d) Linearization in a state space system | b) Models in the electric and mechanic state space<br>c) Changing a transfer function to a state space and backwards<br>d) Linearization in a state space system | |
| 11 | 10 | • Designing a control system in the state space<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>150x2 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | Able to explain the basic concepts of:<br>a) Designing a state feedback controller with a determined position for the pole<br>b) Determining if a system is controllable and observable<br>c) Designing a state feedback controller to fulfill the specifications of | Students are able to analyze and give feedback towards the concept of:<br>a) Designing a state feedback controller with a determined position for the pole<br>b) Determining if a system is controllable and observable<br>c) Designing a state feedback controller to fulfill the | 7% |

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| | | | | | the transient response and steady state error performance | specifications of the transient response and steady state error performance | |
| 12 | 11 | • Digital Control Systems<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time] 150x2 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | Able to explain the basic concepts of:<br>a) Modelling the digital computer in a feedback system, the z-transform and the inverse z-transform<br>b) Determining the transfer function for sampled data's<br>c) Determining the stability of a sampled-data system and determining if the sampling rates to stabilize the system | Students are able to analyze and give feedback towards the concept of:<br>a) Modelling the digital computer in a feedback system, the z-transform and the inverse z-transform<br>b) Determining the transfer function for sampled data's<br>c) Determining the stability of a sampled-data system and determining if the sampling rates to stabilize the system | 7% |

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| | | | | | d) Designing a digital control system to fulfill the criterions of a steady state error and transient response | d) Designing a digital control system to fulfill the criterions of a steady state error and transient response | |
| 13 | 11 | • Digital Control System<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | Able to explain the basic concepts of:<br>e) Modelling the digital computer in a feedback system, the z-transform and the inverse z-transform<br>f) Determining the transfer function for sampled data's<br>g) Determining the stability of a sampled-data system and determining if the sampling | Students are able to analyze and give feedback towards the concept of:<br>a) Modelling the digital computer in a feedback system, the z-transform and the inverse z-transform<br>b) Determining the transfer function for sampled data's<br>c) Determining the stability of a sampled-data system and determining if | 7% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | rates to stabilize the system<br>a) Designing a digital control system to fulfill the criterions of a steady state error and transient response | the sampling rates to stabilize the system<br>d) Designing a digital control system to fulfill the criterions of a steady state error and transient response | |
| 14 | 12 | • Designing and Tuning the PID controller<br><br>[Reference]<br>1. N.S. Nise, M.A, Control Systems Engineering, 7th edition, Wiley, 2015.<br>2. R. C. Dorf and R.H. Bishop, Modern Control System, 12th edition, Prentice Hall, 2011 | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | Able to explain the basic concepts of designing and tuning a PID controller using the Direct Synthesis, IMC, Ziegler Nichols, Cohen Coon and the Reactive Curve method | Students are able to analyze and give feedback towards the concept of designing and tuning a PID controller using the Direct Synthesis, IMC, Ziegler Nichols, Cohen Coon and the Reactive Curve method | 7% |

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| 15 | 13 | • Group Project | Lecturing classes and individual tasks<br><br>[Estimated time]<br>100 minutes | Orientation: Introduction to this week's topic (50%)<br><br>Exercise: Listen to lecture (10%)<br><br>Feedback: Question and answer with the lecturer (40%) | Students are able to participate in answering the exercises prepared by the lecturer to review the materials for the final exam | Students are able to solve and give feedback in answering the exercises prepared by the lecturer to review the materials for the final exam | 9% |
| 16 | Final Exam | | | | | | |

**Assignment Design**

| Week | Assignment Name | Sub-CLOs | Assignment | Scope | Working Procedure | Deadline | Outcome |
|---|---|---|---|---|---|---|---|

| Week | Assignment Name | Sub-CLO | Assignments | Scopes | Working Procedure | Deadline | Outcome |
|---|---|---|---|---|---|---|---|
| 1-14 | In-Class Quizzes, Homework and Simulations | 1-13 | Questions | Summarize the specific week's material and simulations | Individual Tasks | 1 week | Quiz results in class and program design |
| 15 | Group Project | 14 | Final Project | Designing the equipment | Group Task | 1 week | Student Power-point and results of the presentation |

**Assessment Criteria**

| Evaluation Type | Sub-CLO | Assessment Type | Frequency | Evaluation Weight (%) |
|---|---|---|---|---|
| In-class quiz | 1-7 and 8-13 | Evaluation Sheet | 6 | 10 |
| Homework and Simulations | 2-13 | Evaluation Sheet | 12 | 10 |
| Group Project | 14 | Evaluation Sheet | 1 | 20 |
| Mid-Term Exam | 1-7 | Essay Questions | 1 | 30 |
| Final Exam | 8-13 | Essay Questions | 1 | 30 |
| **Total** | | | | **100** |

**Conversion of the students final score**

| Score | Grade | Equivalent |
|---|---|---|

| | | |
|---|---|---|
| 85—100 | A | 4,00 |
| 80—<85 | A- | 3,70 |
| 75—<80 | B+ | 3,30 |
| 70—<75 | B | 3,00 |
| 65—<70 | B- | 2,70 |
| 60—<65 | C+ | 2,30 |
| 55—<60 | C | 2,00 |
| 40—<55 | D | 1,00 |
| <40 | E | 0,00 |

**Rubric(s)**

**A. Criterions for the Group Project Presentation**

| Grade | Quality of Answer |
|---|---|
| 85-90 | If the group is able to present their materials logically, fluently and is able to finish their presentation on time while also being able to answer questions being given by other students or the teacher. |
| 75-84 | If the group is able to present their materials logically and fluently while also being able to answer questions being given by other students or the teacher but is not able to manage their time properly |
| 65-74 | If the group is able to present their materials logically but is not able to logically explain the process of their material |
| 55-64 | The group is not able to present their materials fluently nor logically and is not able to manage their time properly |
| <55 | |

**B. Mid term exam and Final term exam**

| Grade | Quality of Answer |
|---|---|
| 100 | The answers are precise, every definition and main components are included |
| 76-99 | The answers precise enough, all definitions and main components that are needed to answer the question are almost precise |
| 51-75 | The answers are less precise, the definitions and main components that are needed to answer the question are less precise |
| 26-50 | The answers are very unprecise, the definitions and main components that are needed to answer the questions are missing a lot of details |
| <25 | Wrong answer |