Modified SOLO Taxonomy Model for Constructive Alignment in Automatic Control & Signal Processing Education

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***Abstract*— Controls is the engineering field that deals with modeling, regulation and performance assessment of dynamic systems so that they behave according to the desired specifications. Signal processing is the area, which develops methods for processing of sensory data in different areas.**
Achievements in applied mathematics, new sensors and actuator technologies, developments of new IT tools and software create new opportunities in control and signal processing engineering. This in turn implies new challenges and developments in control and signal processing education.
New modified SOLO (Structure of the Observed Learning Outcome) Taxonomy model is developed for automatic control and signal processing education. New model provides a simple, reliable and robust concept, which is well associated with the method of constructive alignment for five levels of understanding. The model is applied for constructive alignment of basic course in automatic control and to mini-lesson in digital signal processing.

I. Presentation of Control Science

A. Introduction

Control systems are widely used in power generation, electrical and electronic appliances, cars and transportation systems, manufacturing processes, computer systems, telecommunications, systems biology, economics and in many other emerging application areas. This in turn necessitates inclusion of control education in the curriculum of electrical and electronic engineering, of mechanical, mechatronic and automotive engineering, manufacturing engineering, chemical engineering, aviation and aerospace engineering as well as in life sciences programs like biomedical engineering, biotechnology and bioengineering, financial engineering and some social sciences like economics, psychology and sociology.

B. The History of Controls

In the 1950's many universities world wide developed courses on basic control using results on Lyapunov stability theorems, the Nyquist stability criterion, Bode plots and others. Later courses on input-single output (SISO) linear systems were introduced dealing with complex s-domain analysis of systems. The courses required a solid background in mathematics, mostly in continuous time domain.
From the early 1960's the theoretical contributions by Hamilton, Jacobi and Bellman (1957) on optimal control, Pontryagin (1962) on maximum principle, Kalman (1961) on optimal filtering and others were included in the courses primarily to electrical and electronic engineering and mechanical engineering programs.
Significant developments in nonlinear control, adaptive control, system identification, stochastic control, fuzzy control, neural-net control, computer-based control, and others in the 1970's, 1980's and 1990's resulted in a variety of courses, research programs and activities related to controls in many universities.
Nowadays control techniques are successfully applied to power plants (wind turbines for example), robotics, aerospace, process control, building automation and many others. Control courses are included in the curriculum of many engineering subjects as well as in the life and social science programs.

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II. Requirements for Teaching and Learning of Control Systems

A. Solid Mathematical Background

The courses on classical control apply mathematical presentations of formal system models which are obtained based on the physical characteristics and the input-output (SISO) relationships of the individual system components. For understanding classical control the teacher and the students suppose to have a solid background in difference and differential equations, mathematical analysis and others.
In modern control formulation any MIMO (Multi-Input Multi-Output) plant under control is represented by the system matrix, the state variable vector, the input and output matrices and the vectors of inputs and outputs. In general it is a set of first order differential equations in matrix-vector form. For understanding modern control the teacher and the students suppose to have a solid background in linear algebra and numerical analysis.
A solid background in stochastic processes is also required for understanding of modern stochastic control theory.

B. Skills in Matlab

Matlab is the language of technical computing, and it is widely used in controls, signal and image processing, computer vision, robotics, communications, computational finance, and in many other areas.
Explanation and visualization of performance specifications of control systems, root-locus method, Bode and Nyquist diagrams, as well as MIMO control system design is impossible without Matlab, which provides a rich alternative of tools not only for control, but also for signal processing and others.
Therefore the teacher and the students should have a solid

background in technical computing using Matlab or similar software.

C. Broad Knowledge of Neighboring Fields

The knowledge of the fields neighboring to control is also very important for understanding of control systems. First of all the knowledge of system components, like sensors and actuators is required. The variety of sensors developed recently is truly remarkable: electrical, electronic, mechanical, optical, chemical, thermal, biological, gas, taste and odor sensors and wearable sensors. Every new field and every new application has now commercially available sensors and actuators.

In addition, the knowledge of signal, data, communication systems and image processing methods for processing data for control as well as optimization methods for calibration of the control systems for optimal performance is also required.

D. Deep Knowledge in the Specific Area, where Control is Applied

Control techniques are applied in many areas and specialized knowledge is necessary to understand the concepts, the notations, the models and the physical rules in each specific area.

For example, for high performance control of wind turbines the knowledge of aerodynamics, drive-line dynamics, generator performance and others is required.

E. Summary

In summary, the basic background requirements for teachers and students in automatic control can be formulated as follows:

- a solid background in such areas of mathematics as differential and difference equations, linear algebra, numerical analysis, stochastic systems and many others
- skills in Matlab
- broad knowledge in the neighbouring fields
- deep knowledge in the specific area

III. Challenges/Problems in Automatic Control Education

For the high performance teaching and learning of automatic control the basic background requirements stated (for both teachers and students) in Section II should be met.

Fulfilment of the requirements in Section II is necessary, but not sufficient condition for the course in automatic control to be successful.

In addition, automatic control education nowadays suffer from the following drawbacks:

- Lack of engineering descriptions of practical design and analysis methods, which are widely used in industry
- Theory and practice are usually not connected, which increases the difficulties in understanding theory
- Application of poor assessment methods, where teaching and assessment are not aligned.

This project offers the solutions of the problems formulated above for improvement of the learning outcomes in control education.

IV. Teaching of Digital Signal Processing

A. Presentation

DSP (Digital Signal Processing) provides a tool kit for processing of sensory data in a large number of areas such as: electrical engineering, radar & sonar, communication, transportation, medical and many others. DSP provides methods and algorithms to process the signals after they have been converted into a digital form. This includes a wide variety of goals, such as: enhancement of visual images, recognition and generation of speech, compression of data for storage and transmission, etc.

The roots of DSP are in the 1960's and 1970's when digital computers first became available, and DSP (which was limited to only a few critical applications) was taught as a graduate level course in many universities as a part of electrical engineering curriculum.

DSP was extended to new applications with the personal computer revolution of the 1980's and 1990's. At that time DSP became a standard part of the undergraduate curriculum.

Nowadays, DSP is a basic skill needed by scientists and engineers in many fields, and it is a part of curriculum in electrical, computer, aerospace and mechanical engineering, biomedical engineering and geoscience, and many others.

DSP has strong ties with communication theory, numerical analysis, probability and statistics, decision theory and electronics.

B. Requirements for Teaching and Learning of Digital Signal Processing

The requirements for teaching and learning of DSP are similar to the requirements stated for control education in Section II and can be summarized as follows:

- a solid background in mathematics, namely in difference equations, linear algebra, numerical analysis, probability and statistics and in many others
- skills in Matlab, where signal processing toolbox is widely used in many applications
- broad knowledge in the neighbouring fields, like electronics and others

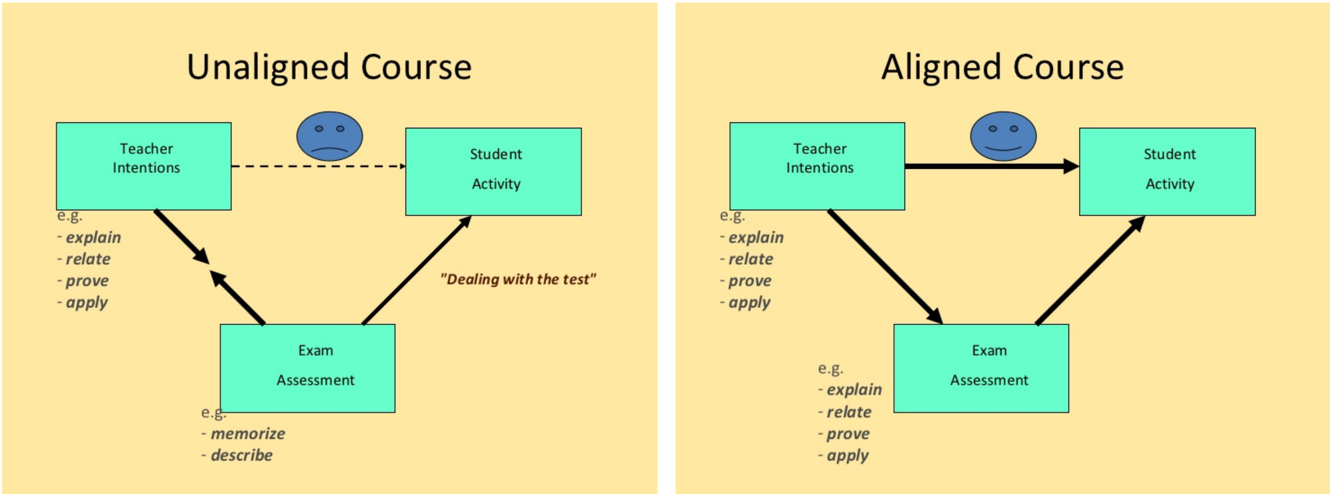
DSP is the area which is closely related to control in terms of tools. DSP and control engineering apply the same design and analysis tools such as Bode and Nyquist diagrams, difference equations, Discrete Fourier Transformation (DFT) and many others.

V. Challenges/Problems in Signal Processing Education

Fulfilment of the basic requirements, formulated in Section IV-B similar to basic requirements stated in Section II for automatic control education is necessary for high performance teaching and learning of DSP.

In addition, DSP education nowadays suffer from the following drawbacks:

- DSP is the area with a wide range of text books and other publications intended for a very specialized audience. Many text books contain complete un-



(a) (b)

Fig. 1. An unaligned versus aligned course

understandable equations, obscure formulations, different terminologies, which describe the same methods and many other things, which make the theory of DSP difficult to understand. Some of the publications are not understandable even by the experts in the field.

- A large gap between the theory, described in the literature related to DSP, see above and practice associated with application of DSP toolbox in Matlab. The students apply DSP toolbox for signal processing without deep understanding of limitations of the tools. Limitations are usually not properly explained in DSP literature, see above.
- Significant misalignment between teaching of the theory and practice of signal processing and assessments.

This project offers the solutions of the problems formulated above for improvement of the learning outcomes in DSP education.

VI. Constructive Alignment as a Tool for Improvement of Teaching and Learning Outcomes in Control

Figure 1 illustrates the essential difference between an unaligned and an aligned course. A mismatch between the teachers intention and the exams assessment is present in an unaligned course. The intention of the teacher is to explain problems and solutions to students, to relate explanations to their previous knowledge, to prove theorems and statements, and to apply their knowledge to new areas, whereas the assessment measures descriptive knowledge only memorized by students.

Intention of the students here is *to focus only on the skills required for the test, and disregard the teachers intentions*. In other words the student is 'dealing with the test', and the connections between intentions of the teacher and the student activities is weak. The students do not have any chance to be engaged in higher-level learning activities, if the course is not aligned.

The solution to this problem proposed in [1] - [3] within the theory of Constructive Alignment (CA) is to constructively align courses with Taxonomy model, described in the next Section.

VII. Taxonomy Models

A number of Taxonomy models are known in the literature. The most known models are Bloom's Taxonomy (and its modifications), Webb's knowledge model and classical SOLO (Structure of the Observed Learning Outcome) Taxonomy model, developed by Biggs [1]. Bloom's Taxonomy model consists of the following levels: Remembering, Understanding, Applying, Analysing, Evaluating, and Creating. Webb's model consists of four levels: Recall, Skills/Concepts, Strategic Thinking, and Extended Thinking. These models are mainly associated with the forms of thinking (and degrees of difficulties) rather than with assessment or formulation of Learning Outcomes.

The SOLO Taxonomy provides a simple, reliable and robust model for five levels of understanding developed in [1], and this model is well associated with the concept of constructive alignment. The principles of this model can be summarized as follows. The pre-structural level is defined as a zero level, uni-structural and multi-structural levels are defined as the levels of surface understanding, where the former is associated with one item and the latter is associated with many items, not connected to each other. Relational level provides links and integrations, missing on multi-structural level, and the extended abstract level as the highest level provides new understanding, creation, generalization and others.

Figure 2 shows detailed explanation of SOLO Taxonomy.

The SOLO Taxonomy model is too general and should be modified and developed as a learning model in the areas of control and signal processing. Notice in addition, that the control system is defined as a number of parts connected to each other to meet desired specifications and multi-structural level of the SOLO Taxonomy model, associated with many items which are not related to each other does not make much sense.

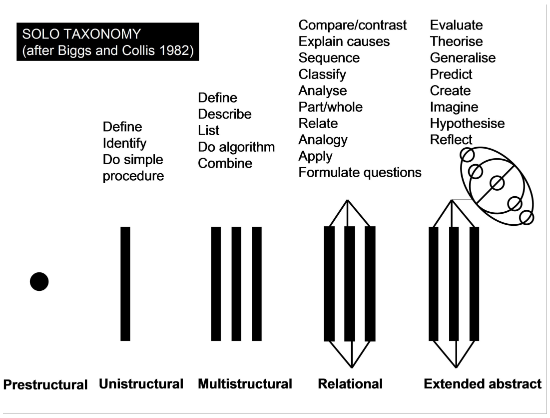


Fig. 2. The SOLO Taxonomy: Overview

A. Modified SOLO Taxonomy Model

The adapted model has the following components:

1) Pre-structural level is defined as initial level of understanding. The student has knowledge, which is relevant as starting point to control and signal processing courses.
2) Uni-structural level provides basic understanding of the subject in terms of terminology, definitions and explanations of simple algorithms.
3) Control system functionality and tools of DSP are considered on the multi-structural level. The student is able to design control systems with desired specifications and apply signal processing algorithms. This level is associated with the design.
4) The relational level is associated with the performance assessment of the control systems and DSP algorithms in the presence of uncertainties and inaccuracies, which are present in different types of applications and redesign (if required). This level includes extensive simulations and application of performance assessment tools, like Matlab Toolboxes for example. This level does not include theoretical study of the robustness.
5) The extended abstract level is associated with the research level in this model, where the student develops new control and DSP methods and uses these methods in different applications.

The differences between the SOLO model, described in [1] and the model described above are the following:

- The relations between the components of the control systems and parts of DSP methods are considered on the uni-structural level already, since this level is associated with the design. The design is associated in turn with the relations between the components.
- The relational level is associated with analysis and robustness of the control system and DSP algorithms, using simulations tools.
- The extended abstract level is associated with the research level and with performance improvement, using theoretical developments.

The list of keywords is also revised in adapted model for each level, compared to general model, described in [1].

B. SOLO 1: The Pre-Structural Level

This level is usually defined as the level, where a student does not have any kind of understanding of the subject, but the student has initial knowledge/background which is relevant to the course. This level is considered in this paper as the initial level or starting point.

C. SOLO 2: The Uni-Structural Level: Understanding Basics

This level is associated with the first step of understanding the subject of control systems and DSP. The student should be able to define and understand basic principles of control systems and DSP. The student is able to use correct terminology, definitions and follow simple procedures, which are mostly based on their previous knowledge. For example, the procedure of filter design in DSP using Matlab toolbox FDA (Filter Design and Analysis) Tool, definition of transfer functions and others. This level is mostly associated with the component level in the control system course, and very little with the system functionality. In DSP this level is associated with the signal presentation, sampling, z-transform, discrete convolution, design of simple filters and others.

The keywords for this level can be presented as follows:

1) SOLO 2 Keywords:

- Define. For example, the student should be able to define and explain basic components/parts and concepts of the control systems and DSP.
- Describe. For example, the student should be able to describe simple control systems, simple filtering and processing.
- Follow simple instructions. The student should be able to follow simple instructions for calibration of existing control systems, changing the filter parameters and others.

Notice that the list of the keywords is not complete and can be extended, describing the basic level of the SOLO model.

D. SOLO 3: The Multi-Structural Level: Understanding Functionality

Control system functionality and advanced tools of DSP are considered on this level. The student is able to deal with a multiplicity, combinations and simple analysis and explanations. The student is able to design closed loop control system, to locate poles and zeros of the transfer functions, and explain the methods. The student is able to apply Discrete Fourier transformation (DFT) in DSP and more complex filter design procedures. The theory is better related to corresponding Toolboxes (Matlab Toolboxes for example) on this level. Simple analysis of the system performance (preliminary performance assessment associated mainly with the design) is also included, but this is not the main point on this level.

1) SOLO 3 Keywords:

- Combine. Design Structure. The student is able to combine parts of the control systems, like sensors actuators in one system unit, close the loop and make the system stable
- Do algorithm. The student will be able to execute filtering algorithms, DFT and others
- Apply Method. The student will be able to apply DSP methods to simple benchmark cases. The student will be able to apply pole placement strategies, frequency response methods and others for control system design

This level is mainly associated with control system design using prescribed specifications, and formal application of DSP methods.

E. SOLO 4: The Relational Level: Performance Analysis, Quantification and Comparisons

This level is associated with analysis, quantification of the performance and redesign of control and DSP algorithms. The performance of the closed loop control system is in focus on this level in control course, and the performance of DFT and filtering methods is in focus in DSP course. This is mostly a quantification level, with extensive simulations, using Matlab and Toolboxes.

1) SOLO 4 Keywords:

- Analyse. The student is able to analyse the properties of control systems using time domain and frequency domain methods. The student is able to estimate frequency contents of the signals and quantify the filtering performance in the presence of uncertainties and inaccuracies.
- Compare. The student is able to compare different algorithms in DSP and controls using statistical methods, for example.
- Integrate. The student is able to integrate DSP methods in control systems, and quantify improvements.
- Relate . The student is able to relate control and DSP methods to specific applications.
- Explain Causes. The student is able to explain the causes of performance deterioration for example in control and DSP algorithms.
- Apply theory (to its domain). The student is able to apply the most suitable control and DSP techniques to specific applications and evaluate the effects.

F. SOLO 5: The Extended Abstract Level as a Research Level in Controls and DSP

This level is practically the research level, often associated with open problems in control and DSP, and recent research results in these areas. The student is able to take open problems in the area of controls and signal processing, develop new control and signal processing methods, which can be considered as contributions to these areas. The student is able to learn new (usually sophisticated) methods (possibly modify these methods), and apply these methods to specific application areas. It means that open problems in application areas are solved with new control and DSP methods, developed/modified by the students.

In order to reach this level the students should get strong support from the Teacher. Usually this level is reached in the areas, where the Teacher has significant research results, and is able to involve the students in the research activity. Guest Lecturers invited for the course may provide good inputs on this level in terms of research results and methods. Notice that Guest Lecturers may provide inputs to this level only, and in order to reach this level the Teacher should complement the lectures with other teaching and learning activities.

1) SOLO 5 Keywords:

- Theorize. The student develops or learns novel control and signal processing methods and algorithms
- Generalize. The student generalizes traditional approaches in controls and DSP, aiming for extension of the application areas
- Hypothesize. The student is able to formulate hypotheses for verification and test the hypotheses
- Predict. The student is able to predict the responses of the control systems, using knowledge acquired on the previous levels
- Reflect. The student is able to change/modify the structure of complex control systems, modify sophisticated DSP algorithms so that they meet desired requirements
- Transfer theory (to new domain). The student is able to transfer theories developed in other areas to control and signal processing

The SOLO model described above can be used for quantification/evaluation of the teaching performance in control and DSP areas. The model shows that teaching based on advanced research results may reach highier/high levels of SOLO Taxonomy.

Intended Learning Outcomes in automatic control and signal processing education should be associated with the SOLO Taxonomy model via keywords, defined above for each level, and communicated explicitly to students, which allows direct evaluation/quantification of the teaching performance.

VIII. Teaching Methods as a Tool-Kit for Constructive Alignment

The following main teaching methods are described in this Section: the lecture and discussion methods, the seminar method, the demonstration method and the laboratory method.

A. Lecture Method

A lecture is an oral presentation of information by the teacher. Lectures is the main method for teaching of automatic control and signal processing. Usually ten lectures are assigned for classical control and five lectures for both digital control and signal processing. The aim of the lecture is

1) To introduce subjects of control and signal processing

2) To present practical applications
3) To present methods, principles, and concepts
4) To prove statements (lemmas and theorems)
5) To introduce demonstrations (for example Matlab demonstrations), to present exercises and so on
6) To review, clarify, emphasise, summarise and so on materials on the subjects.

The lecture as a teaching method has the following disadvantages:

1) Involves one way communication
2) Directed mainly to theory, and does not develop practical skills
3) Poses problems in skill teaching
4) Encourages student passiveness
5) Poses difficulty in gauging student reaction
6) Require highly skilled instructors.

For constructive alignment the lecture method should be complemented by other methods, which develop practical skills. One of such methods, the study assessment method is described below.

B. The Study Assessment Method

A method in which the teacher assigns exercises (for example derivation of mathematical formulas, numerical calculations, simulation exercises and others), reading research papers, books and other materials at home or in the classroom on the lectures. Usually self assessment or peer assessment methods are applied for verification of the results of these assignments.
The aim of the study assessment method is

1) To give theoretical experience (for example mathematical experience) and practical experience (for example design and simulation experience on Matlab) to students
2) To provide review of material
3) To orient students to a topic prior to classroom or laboratory work
4) To increase coverage of material
5) To reduce classroom time
6) To attract individual attention
7) To apply self assessment or/and peer assessment methods (providing opportunities for collaboration)

The study assessment as a teaching method has the following disadvantages:

1) The number of exercises is small and does not cover all the material of the course
2) The results are difficult to evaluate
3) Require careful planning and follow up

Exercises in the study assessment method do not cover usually all the practical experience required for understanding control and signal processing. Therefore some time should be found for additional exercises, and special attention should be paid to Matlab exercises. Matlab is the software, which is widely used in industry for control and signal processing applications.

C. Exercises and Matlab Method

These two methods are usually applied together in sequence in automatic control and signal processing education. First, the students are invited to perform different types of exercises associated to different subjects explained on lectures such as calculation of transfer function of system represented in the state-space form, controller and observer design and many others. In the second step the students are invited to do the same and similar exercises (very often for larger scale systems) using Matlab and toolboxes.
The aim of the exercise method is

1) to develop practical experience in design, analysis and evaluation of the performance of the systems
2) to apply problem based learning
3) to present software for control and signal processing, like Matlab with control and signal processing toolboxes, Maple, Octave and others
4) to verify the results of handmade exercises with the results obtained with Matlab
5) to provide feedback and corrections from Matlab to the exercises
6) to provide opportunities for collaboration on analysing and solving problems in exercises
7) to supplement lectures and laboratory work
8) to determine how well the students understand theory of automatic control and signal processing
9) to increase the interest of students
10) to utilises student knowledge and experience (many students are already familiar with Matlab, when they enter control and signal processing course)
11) to stimulate learning because of high degree of student participation

The exercise as a teaching method has the following disadvantages:

1) Consumes large time
2) Require highly skilled instructors
3) Require computers and licensed software
4) Requires preparation by students
5) Restricts sizes of groups.

Finally, engineering experience with implementation of the control systems and applications of signal processing methods to real signals measured by students is absolutely necessary for control and signal processing education [4]. Therefore the laboratory method should be added to the curriculum.

D. The Laboratory Method

1) Traditional Laboratory: Despite the challenges the application of the theory in a practical laboratory setting will remain as a very important part of the control engineering curriculum. The aim of the laboratory method is

1) to motivate students and stimulate their interest in the subject
2) to deepen understanding through relating theory and practice

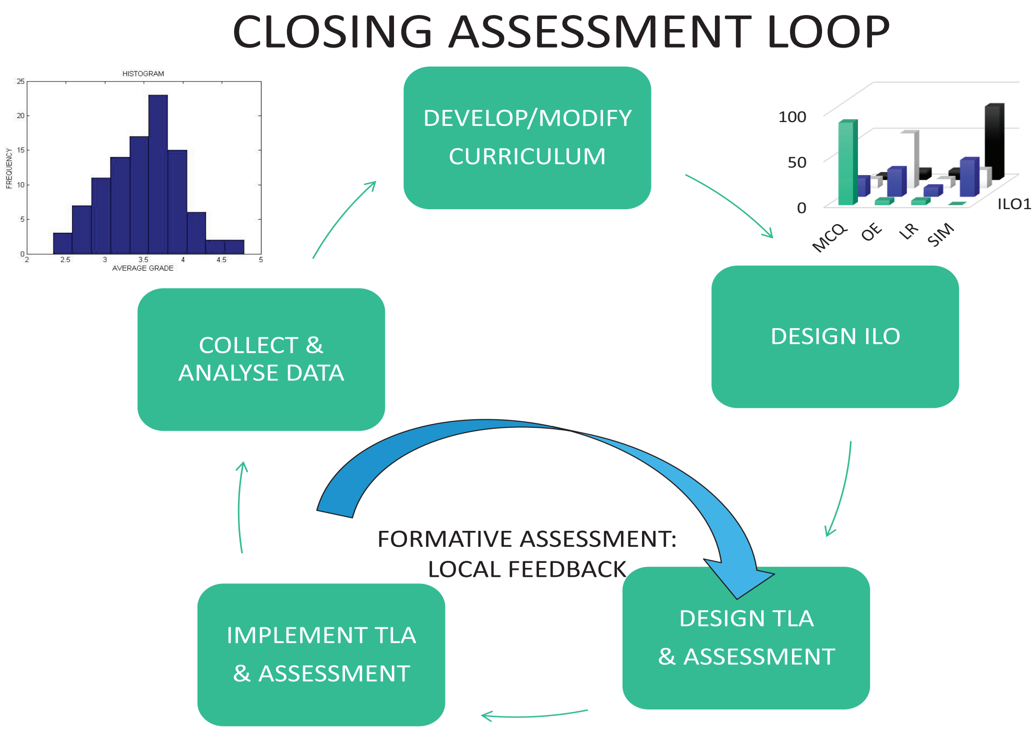


Fig. 3. Data driven closing of assessment loop as step-wise improvement method for constructive alignment. The assessment loop is closed as summative feedback with statistical measurement mechanism described in Section XII-A, see Figure 4. Formative assessment, which is conducted during the learning process is presented as local feedback loop. Design of ILO is described in Section XIII-A, see also Figure 6.

3) to provide opportunities for collaboration on analysing and solving practical problems
4) to develop engineering skills

The laboratory as a teaching method has the following disadvantages:

1) laboratory is expensive to run
2) it requires equipment, which should be renewed often
3) laboratory is time consuming to organize, manage and assess
4) the students are often required to reproduce routine experiments, and to focus on experimental methods rather than on developing skills of data recording, analysis, processing and problem solving.

2) Virtual Laboratory: Many engineering departments developed virtual laboratories, which benefit for student learning, accessability and cost. For example, ReLoad project [5] enables remote web-based experiments in the area of dynamics and control. The combination of real and virtual experiments is also developed in the area of automation and process control [6].

The most promising approach is the development of virtual laboratory, equipped with high fidelity models of real plants. For example, FAST software tool contains high fidelity models of real wind turbines, which are used mainly for research purposes, but can be used in a virtual control laboratory. Notice that virtual control and signal processing laboratory is a low cost laboratory, easy assessable that develops not only practical, but also software skills.

Virtual laboratories will be able to substitute (at least partly) traditional laboratories in the automatic control and especially in signal processing education.

IX. Towards Reflective Teaching: Closing Assessment Loop within the Constructive Alignment and SOLO Taxonomy Concept

The Teacher should choose assessment methods, directly associated with ILO, taking into account SOLO Taxonomy model, for precise measurements of the competencies of the students [3]. To this end the definition of assessment cycle is used. The assessment cycle refers to the process of closing the assessment loop. Closing the loop refers to the use of assessment results to improve teaching and learning activities. It is part of the continuous cycle of collecting assessment results, evaluating the results, and identification of the actions that will improve student learning, implementing those actions, and then cycling back to collecting assessment results, etc. , see Figure 3. The entire process can be seen as reflective teaching with feedback based on assessment methods. Evaluation of assessment results is based on assessment data, which can be qualitative and quantitative.

Qualitative data is associated with descriptive information. This data is often collected using open-ended questions, feedback surveys, summary reports and others and may be difficult to compare, reproduce, and generalize. Analysis

of qualitative data is time consuming, but provide depth. Moreover, qualitative data often shows potential solutions which are not evident in quantitative data, described below. Quantitative data has numerical or statistical values, see Section XII-A. This data use actual numbers (scores, rates, etc) to express quantities of a variable. This data is easy to store and manage providing a breadth of information. Quantitative data can be generalized and reproduced, but must be carefully constructed to be valid.
A number of assessment tools for automatic control and signal processing eduction is listed below and classified in three groups: qualitative, quantitative or dual methods. Assessment methods and ILOs are associated with different levels of SOLO Taxonomy, described in Section VII, which facilitates quantification of the improvements in Learning Outcomes, see Section XII-B.

X. Assessment Tools

A. Multiple Choice Test/Exam

Multiple choice testing or Mupltiple Choice Questions, (MCQ) assesses knowledge based on the correct selection of given potential answers. This type of assessment is usually associated with the lower levels of Taxonomy in automatic control education. However, more complex multiple choice questions and even simulations, see Section X-D provide assessment of more sophisticated thinking on higher levels of Taxonomy. This method of assessment is widely used in automatic control education, where sample MCQ are already created, see the examples below. MCQ taken from the literature are usually not aligned with specific course outcomes.
This is quantitative assessment method.
The method has the following advantages:

1) covers a lot of content or material
2) easy to evaluate and grade
3) objective

The method has the following disadvantages:

1) reduces assessment to provided answers
2) provides assessment for specific ILOs at lower levels of Taxonomy
3) standard MCQs are not aligned with specific learning outcomes

The following MCQ for automatic control education are listed below as examples[1] :
Q1: In an open loop control system

1) Output is independent of control input
2) Output is dependent on control input
3) Only system parameters have effect on the control output
4) None of the above

Correct answer is 2).
Q2: For open loop control system which of the following statements is incorrect ?

1) Less expensive
2) Recalibration is not required for maintaining the required quality of the output
3) Construction is simple and maintenance easy
4) Errors are caused by disturbances

Correct answer is 2).
Notice that the standard MCQ listed above are not very well designed, and show great potential for improvement. Design of relevant MCQ is a difficult task in automatic control and signal processing education, which can be addressed within the concept of constructive alignment.

B. Oral Examination

Oral examination is widely used as a main tool for individual assessment of the knowledge of students in automatic control and signal processing education. This assessment method develops critical thinking on higher levels of Taxonomy, if appropriate questions are created. Design problems and even simulations, see Section X-D can be included in oral examination.
This is qualitative and quantitative assessment method.
The method has the following advantages:

1) creates an open dialog/discussion between the students and the teacher
2) allows students to show their knowledge
3) provides immediate assessment of the knowledge of the students

The method has the following disadvantages:

1) can require a lot of time for both preparations and assessment
2) equally difficult and fair questions for all students is challenging
3) has constraints for responses of the students
4) may be not objective

C. Laboratory Reports/Books

The laboratory in automatic control and signal processing education are usually considered as a part of teaching and learning activities, which develop practical experience rather than an assessment. The laboratory reports become an extremely powerful assessment in addition to learning experience, if this type of activity is aligned with assessment of specific learning outcomes.
The students (or usually a group of students) are required to write reports after laboratories. These reports may be collected in the laboratory books. These books are collected and assessed after each laboratory, providing the grade for students. Laboratory reports may include answers to MCQ, see Section X-A or simulations see Section X-D associated with specific tasks in the laboratory. This assessment method develops critical thinking on higher levels of Taxonomy.
This is qualitative and quantitative assessment method.
The method has the following advantages:

[1] The examples are taken from the ’Control Systems Multiple Choice Questions and Answers Preparation for Competition Exams’ by Abdulrazzaq F. Atto, https://www.scribd.com/doc/149930296/Control-Systems-Multiple-Choice-Questions-and-Answers-Preparation-for-Competiti

1) provides objective assessment of the abilities of students
2) develops skills of critical thinking, technical writing, systematization and generalization
3) simulate real world experiences, which will be useful at future work

The method has the following disadvantages:

1) time consuming to set up and evaluate
2) individual assessment may be difficult

D. Matlab Simulations as Exam

This is a new idea in automatic control and signal processing education, where simulation tasks are assigned to student during the exam. The tasks may vary from the control system and filter design and analysis, using Matlab toolboxes to processing of signals and simulations of high fidelity models, which are very close to reality.
It is required that the student answers questions, resolve problems, perform tasks and take actions etc. according to changing conditions within the simulation. For example, the students change parameters of the high fidelity model of wind turbine (the blade profile, regulator parameters and others) during simulations and describe the outcomes (evolution of turbine power, for example).
The method can be applied together with the control or signal processing design assignments for verification of the results, using simulation tools.
The method is useful for assessing a wide range of software skills, knowledge of control systems and signal processing as well as the knowledge in different application areas, wind turbines, electricity networks, vehicles and others. This assessment method develops analytical skills on higher levels of Taxonomy.
This is a quantitative and qualitative assessment method.
The method has the following advantages:

1) students develop skills both in automatic control and signal processing by using Control Systems and Signal Processing toolboxes, and in software/computer engineering
2) simulate and stimulate real world experiences with high fidelity simulation models
3) cheaper than laboratory assessment
4) develops practical simulation skills, which will be useful for future work
5) simulations can be done remotely, which saves classroom time and provides flexibility for students
6) some simple simulations can even be included in the multiple choice or oral exam
7) the method is objective

The method has the following disadvantages:

1) time consuming to set up
2) requires equipment (computers with licensed software, which may be expensive)
3) develops skills for specific software tools only, for example Matlab, Maple, Octave, Pyton and others.

E. Embedded Assessment in Curricular Activity as Formative/Local Feedback Loop

Assessment methods can be embedded (as formative assessment) in different types of teaching and learning activities in automatic control and signal processing education. Formative assessment may occur within classroom lectures, seminars, exercises and any other curricular activity. Class room assignments such as simulations described for example in Section X-D, linked to student learning outcomes serve as powerful formative assessment instruments, which provide local feedback loop (immediate refection) to the teacher. Such a feedback is for immediate application for improvement of teaching and learning activities, see Figure 3.

XI. Step-Wise Implementation of Constructive Alignment: A Proper Choice of Assessment Methods in ILO Framework

Designing forms of assessment, which measure the competencies associated with ILO is the most important step in the process of constructive alignment. Learning outcomes presented in Section XIII-A should be assessed using the assessment tools presented in Section X in a optimal way in order to achieve the best learning performance. The solution is not unique and the teacher needs to carefully judge which form of assessment matches best each specific ILO in the presence of constraints. One of the solutions is presented in Figure 6.
Implementation of constructive alignment can be seen as step-wise process with feedback associated with assessment. In this case the best constructive alignment is achieved after a number of iterations (steps). This method can be called as step-wise constructive alignment with high performance guaranteed by feedback.

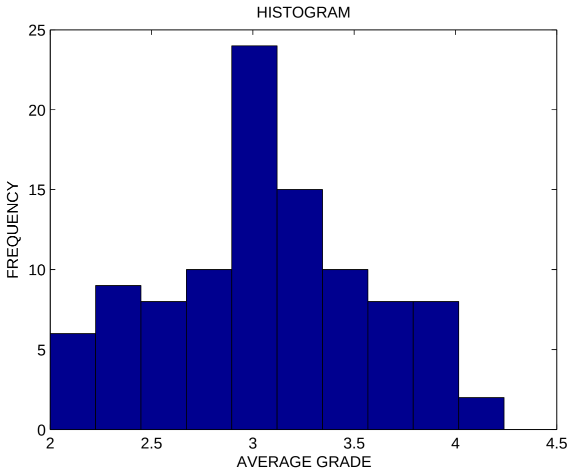
XII. Measurements of Improvements in Learning Outcomes

A. Academic grading in Sweden

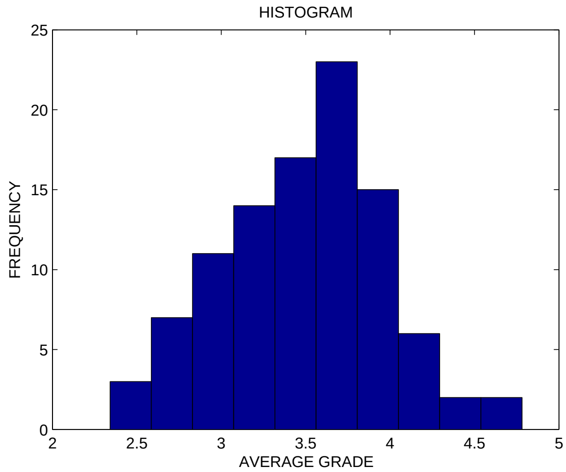
The following standard grading scale is applied in Swedish universities :

- VG - Väl godkänd (Passed with distinction)
- G - godkänd (Passed)
- U - Underkänd (Fail)

In the fields of engineering and technology, the passing grades of VG and G are commonly replaced with 5, 4 and 3, and the grading scale becomes $2, 3, 4, 5$, where grade 2 is fail, and grade 5 is associated with 'passed with distinction'. The same grade system can be applied for assessment of each learning outcome individually. The final grade for the course can be worked out as an average value of all the learning outcomes, which is referred below as OLO (Observed Learning Outcome). Notice that a weighted average can be applied for the case where some of the OLOs are more important than the others.



(a)



(b)

Fig. 4. The Figure shows two normal distributions of the average grades for a number of OLOs, which are assessed individually for 100 students. Subplot (a) shows distribution before the changes, and subplot (b) shows distribution of the grades after the changes. Statistical method of quantification of the changes is associated with two-sample t, where the hypothesis that the average values of two distributions are the same is taken as a null hypothesis. This hypothesis is tested against alternative hypothesis that the average values of two distributions are different. The average value of OLO grade before the changes is 2.99, and the average value after the changes is 3.48 with approximately the same standard deviation of 0.49. Two sample t test indicates rejection of the null hypothesis at a significance level of five per cent, and shows statistically significant improvement of OLO after the changes.

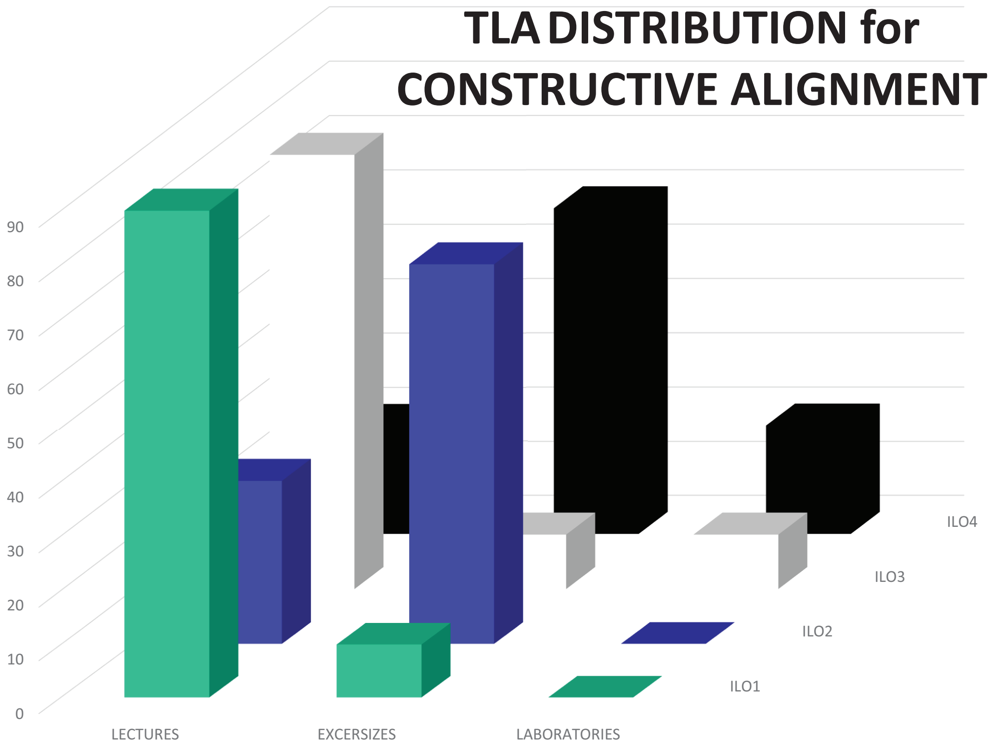


Fig. 5. First four ILOs, plotted with green, blue, white and black colours respectively and described in Section XIII-A are presented as normalized combinations of three TLA: Lectures, Exercises and Laboratories. The sum taken over TLAs is 100 percent for each ILO, which provides complete coverage for all the ILOs.

B. Quantification of the Improvements of a Number of Learning Outcomes

Suppose that a number of OLOs, described for example in Section XIII-A for a large group of students was assessed with grading described in Section XII-A. Suppose also that the Teacher made changes in TLA, learning outcomes and/or assessment methods, see Figure 3, and wants to quantify the improvements. A new statistical method for quantification

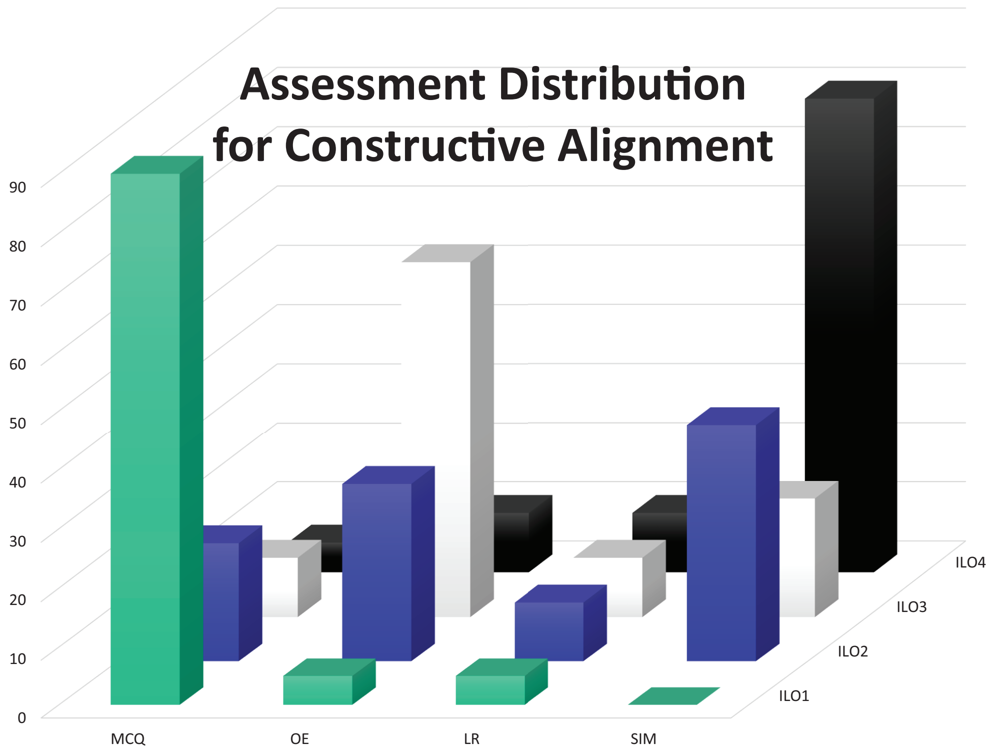


Fig. 6. Constructive alignment for first four ILOs described in Section XIII-A with four normalized assessment methods described in Section X, where MCQ, OE, LR and SIM stand for Multiple Choice Questions, Oral Exam, Laboratory Reports and Simulations respectively. The alignment for ILO1-4 are plotted with green, blue, white and black colours respectively. The sum taken over assessment methods is 100 percent for each ILO, which provides complete assessment for all the ILOs.

of the improvements in OLO is proposed in this paper. The method is associated with the hypothesis testing of the average grades of OLOs before and after the changes, see Figure 4.

Notice that OLO may have different weighting factors, when calculating average grades. The weighting factor for each Learning Outcome (for calculation weighted average) can be chosen using SOLO Taxonomy model, developed in Section VII. For example, each ILO can be associated with certain SOLO Taxonomy level, which in turn has different weighting factors (or the range of weighting factors), see Section XIII-A and Section XIV-B.1.

Statistical method is associated with two-sample t hypothesis test, where the hypothesis that the average values of two distributions (plotted in Figure 4) are the same is taken as a null hypothesis. This hypothesis is tested against alternative hypothesis that the average values of two distributions are different, see Appendix for definition of different alternative hypotheses. The average value of OLO grade before the changes is 2.99 for 100 students, see Figure 4(a), and the average value after the changes is 3.48, see Figure 4(b) with approximately the same standard deviation of 0.49. The two-sample t hypothesis test indicates rejection of the null hypothesis at a significance level of five per cent, and shows statistically significant improvement of OLO after the changes.

Notice that two sample t test for the case of unequal variances is developed in [7]. The same statistical method for quantification of the performance of frequency detection algorithms was proposed in [8].

XIII. Implementation of Constructive Alignment in Introductory Course of Automatic Control

A. Formulation of ILO

Overall goal of the Automatic Control Introductory course is the following:

To acquire a deep understanding of the techniques in automatic control, which will help students to solve practical problems.

This overall goal of the course can be scoped down to Intended Learning outcomes (ILO) (associated with SOLO Taxonomy model, see Section VII), which can be formulated as follows. After this course the students will be able:

- to describe and explain basic concepts of control theory, SOLO 2 (describe), SOLO 3, (explain).
- to use block diagrams, transfer functions, state-space representations (and relations between those) for description of control systems in different applications SOLO 2 (describe, do simple procedure).
- to explain basic concepts of the control system stability, associated with the stability of differential and difference equations, SOLO 3 (explain).
- to quantify the performance of open and closed loop systems using impulse response, step and frequency

responses, SOLO 4 (analyse).

- to design feedback and feedforward control strategies which provide desired properties to closed loop system, SOLO 3 (design).
- to quantify the performance of closed loop systems using time domain and frequency domain methods, SOLO 4 (analyse).

Each ILO listed above is associated with the SOLO Taxonomy model developed in Section VII via keywords. These ILOs together with the SOLO model should be explicitly communicated to the students in the beginning of the course. Notice that modified SOLO model can be included in the course description as a supplementary material.

B. TLA Design for Constructive Alignment

After defining ILO the Teacher should choose a proper combination of TLA to cover all the learning outcomes. The process is illustrated in Figure 5, where TLAs are designed for first four ILOs described in Section XIII-A. Corresponding distribution of the assessment methods is presented in Figure 6.

XIV. Mini-Lesson: Discrete Fourier Transformation in Digital Signal Processing

Revising Teaching of Discrete Fourier Transformation: From Traditional to Generalized Description

A. Traditional Description of Discrete Fourier Transformation

Discrete Fourier Transformation of a signal y_k is usually presented in the following complex form in signal processing and control literature:

$$DFT = \sum_{q=-n}^{q=n} c_q e^{iqx_k} \quad (1)$$

$$c_q = \frac{1}{w}\sum_{k=1}^{w} y_k e^{-iqx_k} \quad (2)$$

where q is the frequency, c_q are Fourier coefficients, $i^2 = -1$ and $x_k = k\Delta$, $k = 1, 2, ...$.

This description is widely used in the literature and applies advantages of complex variable, which resulted in such a neat form of the description of DFT (Discrete Fourier Transformation).

This description is usually presented without proof, and the students have difficulties to understand the meaning of DFT and its limitations, asking questions about negative frequencies.

B. Generalized Description

1) Overall Goal & Intended Learning Outcomes:

Overall goal of the lecture is the following:

To acquire deeper understanding of Discrete Fourier Transformation via generalized form and numerical methods, which will help students to solve practical problems.

This overall goal of the lecture can be scoped down to Intended Learning Outcomes (ILO) (associated with SOLO Taxonomy model, see Section VII), which can be formulated as follows. After this lecture the students will be able:

- to derive and analyse DFT (Discrete Fourier Transformation) with least-squares method, SOLO 3 (design), SOLO 4 (analyse).
- to calculate the sums of trigonometric functions, SOLO 2 (do simple procedure/follow simple instructions).
- to understand and utilize the properties of Strictly Diagonally Dominant (SDD) matrices, SOLO 2 (describe).
- to analyse generalized description of DFT, and apply SDD property for calculation of the parameter vector, SOLO 4 (analyse), SOLO 5 (generalize).
- to derive and apply complex compact form of DFT with understanding all the limitations, SOLO 3 (derive), SOLO 5 (new understanding).
- to derive and quantify the performance of the Richardson algorithm for solving systems of algebraic equations with SDD matrices, SOLO 3 (derive), SOLO 4 (analyse).
- to derive and quantify the performance of the second order Richardson algorithm for solving systems of algebraic equations with SDD matrices, SOLO 3 (derive), SOLO 4 (analyse).
- to derive and quantify the performance of high order algorithms for solving systems of algebraic equations with SDD and positive definite matrices, SOLO 3 (derive), SOLO 4 (analyse) , SOLO 5 (new understanding).

Each ILO listed above is associated with the SOLO Taxonomy model developed in Section VII via keywords. These ILOs together with the SOLO model should be explicitly communicated to the students in the beginning of the lecture. Mini-lesson is designed using the following literature [7] - [12].

This mini-lesson shows that

- research results included in teaching allow to reach higher levels of SOLO Taxonomy
- DFT can be explained using previous knowledge of the students
- DFT can be generalized
- extensions of DFT can be used in different applications, such as electrical engineering applications (for example DFT can be used for frequency estimation in smart grids)
- there exist possibilities for improvements in DFT, where students will be able to modify DFT themselves for performance improvement for example.

XV. Conclusion

This paper showed that the modification of SOLO (Structure of the Observed Learning Outcome) Taxonomy model is needed for automatic control and signal processing education. It was shown that new SOLO Taxonomy model developed in this paper can be integrated into the method of constructive alignment. The model is successfully applied for constructive alignment of basic course in automatic control and to mini-lesson in digital signal processing.

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XVI. APPENDIX A: MATHEMATICAL BACKGROUND OF THE METHOD OF QUANTIFICATION OF THE IMPROVEMENTS

Two sample t test compares two independent sample averages. Let x and y be two normally distributed variables described by mean values $\overline{x}$ and $\overline{y}$ and sample variances S_x and S_y drawn from the size n sample and size m sample respectively.

• A null hypothesis is: $H_0 : \quad \overline{x} = \overline{y}$. The variances σ_x^2 and σ_y^2 are assumed to be unknown but equal.

The following statistic

$$t = \frac{\overline{x} - \overline{y}}{S\sqrt{1/n + 1/m}} \quad , \tag{3}$$

$$S = \sqrt{\frac{(n-1)S_x^2 + (m-1)S_y^2}{(n-1)+(m-1)}} \tag{4}$$

follows a Student distribution with $n + m - 2$ degrees of freedom.

• Alternative hypotheses and critical regions are the following [7]:

$$\begin{aligned} H_{A1} &: \quad \overline{x} > \overline{y}, \quad |t| > t_{1-2\alpha, n+m-2} \\ H_{A2} &: \quad \overline{x} < \overline{y}, \quad |t| > t_{1-2\alpha, n+m-2} \\ H_{A3} &: \quad \overline{x} \neq \overline{y} \quad\ \ |t| > t_{1-\alpha, n+m-2} \end{aligned}$$