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Analysis of constructive alignment according to the SOLO taxonomy in an undergraduate automatic control course

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Abstract

An undergraduate basic course in automatic control is evaluated with respect to constructive alignment using the SOLO taxonomy. This is done by classifying problems in course exercises, labs and exams as well as studying exam results with respect to levels of the taxonomy. The results suggest that the course is fairly well aligned. However, the amount of exam questions on the relational level was found to have some undesirable variation.

keywords: SOLO Taxonomy, Constructive Alignment, Teaching Automatic Control

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1 Introduction

There are many methods to analyze the contents of a course. This report works with the SOLO-taxonomy which splits the contents of the course into five levels of complexity depending on the answer expected by the student. A related concept is constructive alignment which is a principle for how the different parts of a course should be designed in order to make the course coherent.

The goal of this work is to study how well constructive alignment is implemented in the Basic Course in Automatic Control, as well as to investigate how the different levels in the SOLO taxonomy are represented. This is done by analyzing the taxonomy levels of exercise sessions, laboratories, exams and comparing those to the intended learning outcomes.

The motivation behind the choice of this project is that it is interesting to investigate how the theories are applied to the largest course at the Department of Automatic Control. Furthermore, it is of interest to look in to whether a method with constructive alignment and the SOLO taxonomy is suitable when investigating a course. Although, this report gives by no means a comprehensive account of this issue, rather it provides a practical description. Finally, as the Basic Course is taken by almost every program at LTH and given three times a year, there is sufficient data to perform this kind of analysis.

2 Theory

This section provides a brief overview of the two main concepts used in this report, the SOLO taxonomy and constructive alignment. The theory is limited to only these concepts and the reader is referred to the referenced literature for further study.

2.1 SOLO taxonomy

SOLO stands for "structure of the observed learning outcome" and is a way of analysing the response a student gives to a particular learning task. This analysis can be used to describe different levels of understanding based on the structure of the student's answer.

Before SOLO was purposed, there was research in the cognitive development of children. Different levels of cognitive development were determined by the age of the child. Biggs, the creator of the SOLO taxonomy, calls this hypothetical cognitive structure (HCP)[3]. HCP tries to describe the cognitive capabilities of the student that do not change over time. HCP is not measurable and is inherent to the student. HCP is in this way somewhat similar to what IQ tries to measure. Biggs was inspired by HCP when he created SOLO, but instead of focusing on the student's cognitive capabilities he concentrated on the student's response to a specific learning task.

SOLO can depend on many different circumstances such as motivation and prior knowledge but has an upper limit determined by the student's cognitive capabilities. SOLO's dependence on the circumstances makes it possible for education to affect SOLO, this is in contrast to HCP were the student capabilities are static. SOLO is, therefore, interesting to use when measuring learning and understanding in a teaching environment. It gives an indication of how well the students understand the taught material. The possibility to measure understanding is of particular interest for teaching at the faculty of engineering, were having a thorough understanding is important. It is important for the engineer to solve new unforeseen problems, he or she must synthesise knowledge, and that requires a deep understanding of the subject. SOLO can be measured by looking at the responses of the student in different learning tasks.

To measure the students' understanding of the subject using the SOLO concept a standard way of categorization is useful. Hence, as a means to fill this void, Biggs created the SOLO taxonomy. The SOLO taxonomy is based on the student's ability to reason about what he/she has learned and consists of five levels of increasing complexity: [3]

- *Prestructural (P)* understanding means that when asked a question, the answer is either not related to the question or just a rephrasing of it.
- *Unistructural (U)* knowledge is when the answer contains only one fact and a conclusion is drawn based on that fact. Or similarly, the answer concerns only one aspect of the question.
- *Multistructural (M)* answers contain many facts related to the question, but the facts are presented separately. Different aspects are brought up, but answers do not include any intertwining of these aspects. The different aspects can be conflicting with each other, but the conclusion does not contain any resolution of these inconsistencies.
- *Relational (R)* knowledge implies answers that contain many facts, which are discussed and related to each other. The different aspects are intertwined and give a consistent answer with a non-contradicting conclusion.
- *Extended Abstract (EA)* means that the student's reply contains many facts, that may contradict each other. These facts are discussed in a manner, such that, depending on how these facts are valued different conclusions can be drawn. The conclusion may contain many possible answers to the question. The student can also generalize from facts to new abstract models.

For an engineering student to reach the level of understanding discussed above, it is desirable that courses reach a level of complexity in parity with the Relational or Extended Abstract levels.

Although the SOLO taxonomy is primarily a conceptual framework, it can be useful as a means of designing and assessing courses. As an example, course objectives can be checked to ensure that the course contains a range of learning activities where the student learns both Unistuctural and Multistructural skills. Furthermore, the SOLO taxonomy may be useful when creating exams to assure a suitable difficulty level.

2.2 Constructive alignment

Many teachers are concerned with students focusing too much on the examination instead of acquiring long term knowledge. This approach is of course fully understandable from the students' perspective. Hence, exams should be designed to reflect the most important aspects of the course. Formalizing and communicating these aspects is done through the *intended learning outcomes* in the course description. However, since a course is comprised of several components there is a clear risk that a misalignment occurs. The concept of *constructive alignment* stresses the importance of aligning different course components, such as intended learning outcomes, teaching and examination. It is easy to forget the constructive part, suggesting that learning is constructive, i.e. that is it is based on the students' activity [2]. This is an important part as it is not enough to instruct the students. To actually learn something they have to try themselves.

Testing if the students have learned what they should during exams seems self evident. But it is common that the examination instead checks who learned the most [2]. It is not only logical to check if the students have learned what they should, it is also seems it is more effective in motivating the students [4].

Intended Learning Outcomes

Intended Learning Outcomes (ILO) are statements that specify the level of understanding and performance the student is expected to accomplish after going through the teaching/learning activities. These ILO can be described using different verbs to indicate the level of understanding needed to fulfill the ILO. Examples of such verbs are explain, apply, reflect and evaluate.

Teaching/Learning Activities

Teaching/learning activities (TLA) are activities which help the student to build his or hers knowledge. For a course that implements constructive alignment, TLA should assist the student in constructing the knowledge stated in the ILO. As a desirable side effect of TLA, students can form knowledge not stated in the ILO.

Assessment tasks

Assessment tasks (AT) is tasks used by the examiner to assess the student's knowledge. In an aligned course these tasks shall allow the students to show that he or she has attained the knowledge described in the ILO.

3 Automatic Control Basic Course

The basic course in automatic control is a mandatory course given to several engineering programs at LTH. A relatively large amount of students ($\sim$600) take the course every year. These students have various backgrounds in mathematics. The course consists of 15 lectures, 3 labs and 15 exercise sessions during one semester. The exercises are split into nine different sections.

The aims of this course [1] are to give knowledge about the basic principles of feedback control and to give insight into what can be achieved with control, including both the possibilities and limitations. To pass the course one must pass all the laboratories and pass the exam. The grade is decided by the result on the exam.

3.1 Intended Learning Outcomes

This section presents and briefly discusses the intended learning outcomes [1] in order to later compare it to the course material with respect to ST and CA in the following sections. Furthermore, the learning outcomes have been classified according to the SOLO taxonomy.

Knowledge and understanding
For a passing grade the student must

- be able to define the fundamental concepts of control (U)
- be able to linearise nonlinear dynamical models (U)
- be able to compute the relations between dynamical models in the form of transient responses, transfer functions, differential equations on state-space form, and frequency responses described with Bode or Nyquist diagrams (M)
- be able to analyse dynamical systems with respect to stability, robustness, stationary characteristics, controllability, and observabilility (U)
- be able to implement controllers using discretization of analog controllers (U)

Competences and skills
For a passing grade the student must

- be able to design controllers from given specifications on robustness and performance based on models on state-space form, transfer function form, Bode diagrams or Nyquist diagrams (M)
- be able to design controllers based on cascade connections, feed forward, and delay compensation (M)
- be able to evaluate controllers by analyzing transient and frequency responses, and via laboratory experiments on real processes (R)

Judgement and approach
For a passing grade the student must

- understand relationships and limitations when simplified models are used to describe complex dynamical systems (R)
- show ability for teamwork and collaboration at laboratory exercises (U)

The course is hence composed of 50 % unistructural, 30 % multistructural and 20 % relational intended outcomes. As can be seen the Automatic Control basic course is intended to be a fairly practical course. The focus is on being able to do things. However, note that for a passing grade the student should reach a relational level of understanding as well.

3.2 Related courses

The basic course is not a stand-alone course. The course ”Control Theory” is meant to be a supplement to the course covering more theoretical aspects of the material presented in the basic course. However, the basic course is given three times a year, while control theory is only given once a year. Furthermore, a higher theoretical understanding of each concept does not necessarily mean a better relational understanding.

In the more advanced courses given at the department the students have the opportunity to do individual projects, both practical and theoretical. It is by the authors' experience during these projects that the students encounter more challenges at the R and M levels. Note however that most students taking the basic course will not take more courses at the department.

In summary, there are plenty of courses to deepen the understanding for the students that want to, but there are many students that only take this course in automatic control.

4 Method

Exercises, labs and exam problems were studied in order to evaluate the course with respect to the SOLO taxonomy. The chosen approach was to classify the problems according to the three middle levels in the taxonomy, the reason for excluding the lower and upper levels was that they were not represented in the problems. A similar classification of undergraduate chemistry courses was presented in [5].

In addition to our own empirical investigation an interview was conducted with Professor Tore Hägglund who is responsible for the course. The interview was structured so that at first a brief introduction to our problem domain was given. Then a number of open questions were asked to explore the thought process in regards to designing, improving and giving the course. Finally, our empirical results were discussed.

4.1 Classification

This section describes how the problems were classified as either unistructural (U), multistructural (M) or relational (R). The classification was done by matching each problem with the category in the SOLO-taxonomy that best fits the type of knowledge required to solve the problem.

It was typically quite easy to classify problems for level U but more difficult to choose between M and R. This lead to some discussion among the group members but in the end we came to consensus. One rule of thumb that was used was that if a lot of information or clues were given to the student in the problem formulation, then the problem was more likely on a multistructual level. However, if more freedom was given to the student, then the problem encouraged reasoning and discussion and was more probably on a relational level. Bellow follows a general description of the classification method.

4.1.1 Unistructural (U)

A typical unistructural problem is one where the student has to apply a single technique or concept taught in the course to a straightforward problem, e.g. linearize the system, place the poles with state feedback according to specifications, draw the bode diagram for a given system. This type of problems could still be hard due to mathematical difficulties, but the level of abstraction required to solve them is low. Typical problem phrases for U were "compute", "write" and "choose variable x so that $f(x) = y$ ".

4.1.2 Multistructural (M)

Multistructural problems were tasks where the student has to relate and compare different situations using a combination of techniques taught in the course. For instance when matching a set of systems to a set of system responses and comparing the differences, or when explaining why one controller design might work but not another. Typical problem statements for this level were: "pair x's with y's and motivate your answer", "true or false? motivate your answer" and "what happens when ... ?".

4.1.3 Relational (R)

These are problems for which sparse information is provided to the student, usually related to real-world applications where the student has to make a decision on a suitable controller design taught in the course, while also motivating and discussing the choice. Typical problem phrases for R were: "for the system x, design a controller fulfilling a set of conditions" and "a design problem has occurred, what has gone wrong? come up with a solution".

4.2 Data analysis

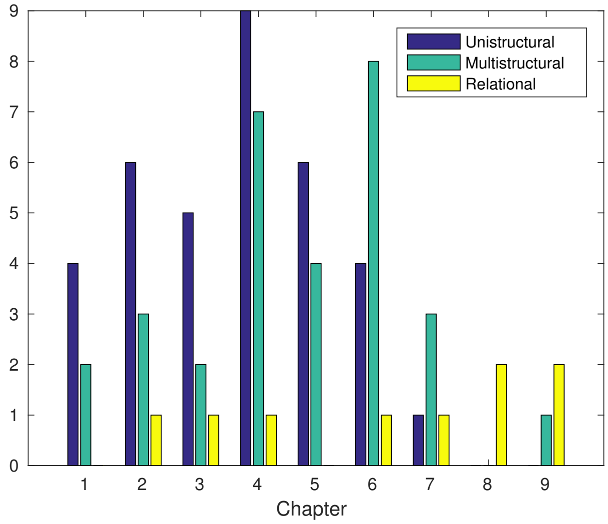
The obtained problem-classification data was used to compute the level distribution among exercise chapters, laboratory sessions and exams. The overall level distributions were also computed and can be seen in the Results & Discussion section. These results were then correlated with respect to awarded exam points and results, to each other and also with the intended learning outcomes.

5 Results & Discussion

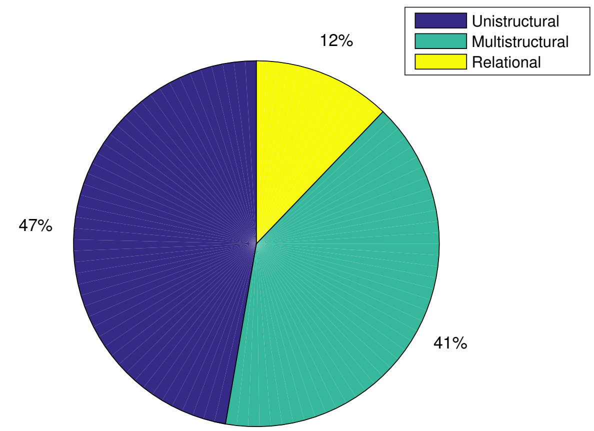
In this section the results will be presented and discussed. The results are examined for each course component individually.

5.1 Exercises

The taxonomy level of the exercises can be seen in Figure 1a-1b. Over the whole course the distribution is quite aligned with the course outcomes. There is also a clear trend with the course chapters which are taken chronologically. In the beginning of the course the student has to learn basic concepts necessary for the later chapters, leading to more U type problems. In the later chapters reasoning, comparison and independent work are encouraged. In the last chapters real world applications are introduced, being reflected by the increased number of M and R problems. The authors realize that there seems to be some thought behind how the problem level is increasing throughout the course.



(a) The number of exercises in each of the three categories of the SOLO taxonomy. We can see that exercises at a relational level starts fairly early, but there are not that many of them. An exercise is considered a certain level if one of its subproblems is on that level.



(b) The distribution of different levels of the exercises for the entire course.

Figure 1: Exercise problems classified according to the different levels of the SOLO-taxonomy.

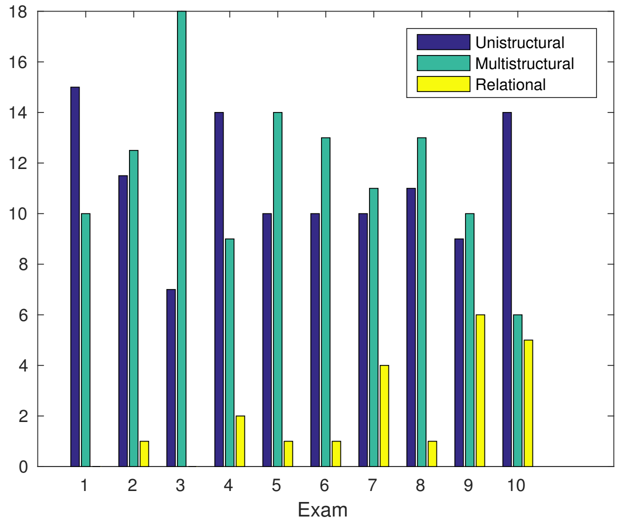
5.2 Exams

The studied exams were the 10 most recent exams given in the course, the obtained distributions are present in Figs. 2a-2b. As can be seen, the number of R and M questions in the exams have a large spread, while the the number of U problems are more consistent. The mean distribution over the years is quite consistent with that of exercises and intended course outcomes. It should however be noted that exams with more R and M questions are not necessarily more difficult, but they encourage more reasoning and independent work by the student. It is however clear that some work can be put in decreasing the variation in R and M, so that the students encounter similar problems each year, also leading to an improved course alignment.

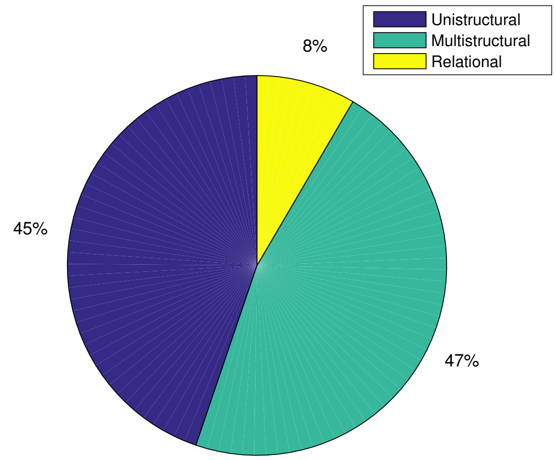
In Figure 3 the results of exam #9 and #10 can be seen. These were the exams were full results were available and there were sufficiently many questions on each level. There is quite a clear trend that how well the students does on the questions decreases as the questions move up the SOLO taxonomy. Thus looking at this limited amount of data, it seems like there actually is a increase in difficulty with an increase in SOLO level. This further motivates the possibility of using the SOLO taxonomy as a judgement of difficulty of different exams.

5.3 Lab exercises

As can be seen in Figure 4, approximately 70 % of the lab exercises have been classified to be at a unistructural level. The remaining 30 % is comprised of 10 % classified as relational and 20 % classified as multistructural. In regards to this there are however a few key points that should be noted. First of all, the labs are in themselves to a large degree designed to solve real world problems and require a relational understanding when creating the lab-manual. The lab-manual does however guide the students to such an extent that the actual task posed to the student often is simple to execute. For example, change a parameter and see what happens. Even though the intention when creating the lab-manual is to show complexity and stimulate a deepened understanding, the actual questions end up being very simple.



(a) The distribution between the points of different levels for the 10 most recent exams. It can be seen that the amount of points in the different categories can vary quite a bit between different exams.



(b) The average distribution of points for the different levels of the SOLO-taxonomy.

Figure 2: Exam problems classified according to the different levels of the SOLO-taxonomy.

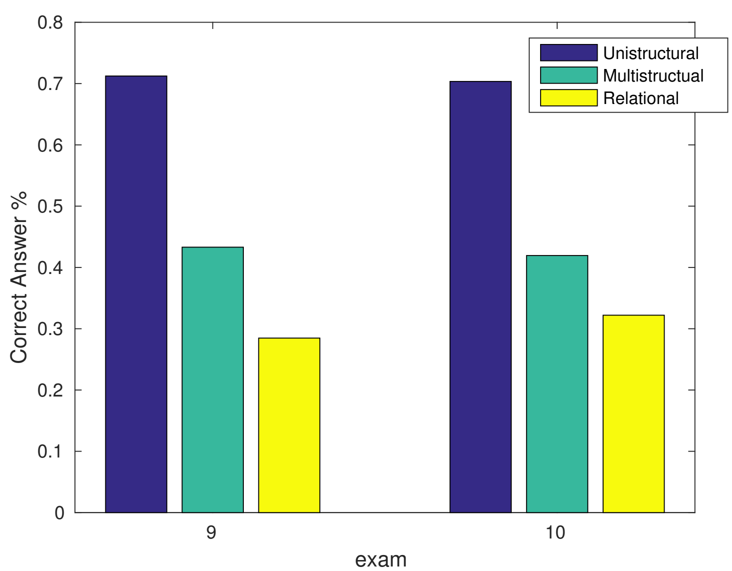
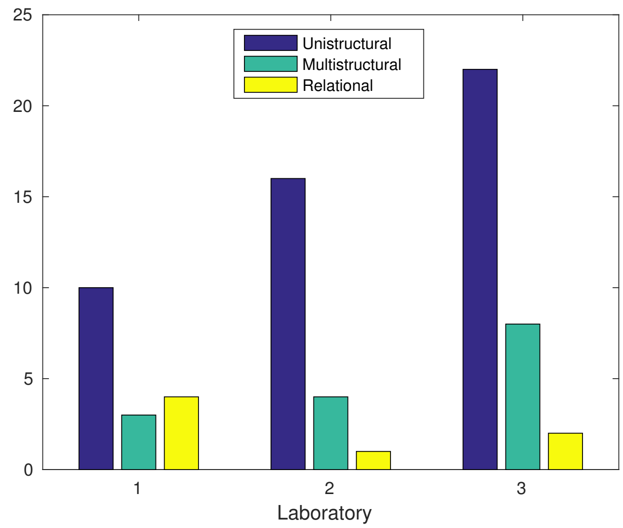
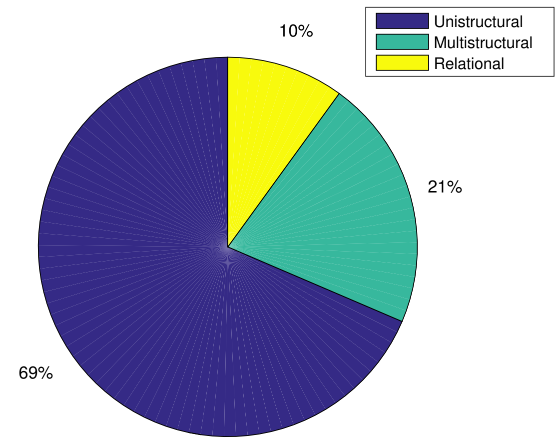


Figure 3: How well students did on different levels on exam #9 and #10.



(a) The number of lab exercises in each of the three categories of the SOLO taxonomy.



(b) Distribution of different SOLO-levels in lab-exercises for the entire course.

Figure 4: Lab exercises classified according to the different levels of the SOLO-taxonomy.

Secondly, the labs are designed to make sure that the students have good instructions and avoid being stuck and are therefore fairly detailed. This results in many questions describing simple steps, such as "Enter command X in Matlab". Several of these simple steps could be bundled together or are repetitive and will therefore inflate the number of unistructural questions. Furthermore, it should be noted that the questions classified as relational often appear in the summary questions towards the end. This, in part, explains why the percentage of multistructural problems is lower than in both the regular exercises and the exams. Also, the first lab is exploratory in its nature and to a larger extent asks the student to think about the process. For completeness it should also be mentioned that some of the lab-exercises are to be done as preparatory exercises and is in that sense closer to regular exercises. This has been disregarded in the analysis.

Thirdly, the instruction "press a button" might be very easy and is easily classified as a U level task. However, the process of understanding what happens and combining theory and practice might still be very hard. This is not captured by our application of the SOLO-taxonomy on the labs.

5.4 Interview with Course Coordinator

An interview was made with the course Coordinator (CC) in order to show our results and also listen to his views on course design. The CC commented that the course is fairly old and only small changes in the material have been made gradually during the years, this is due to the large amount of students (∼600) taking the course every year. In addition, these students have various backgrounds, in terms of previous knowledge, so changes have to be made with caution. No particular action had been taken to make the course aligned according to the taxonomy other than common sense and many years of experience giving the course.

The overall high level of U questions were explained by the fact that the course is at a basic level and a large amount of different topics/tools are introduced in a fairly short time.

The exercise results were in line with the CC's experience and it was intentional to first introduce a lot of concepts in the beginning of the course and to increase the complexity of the problems towards the end.

The CC commented on the low number of R in the lab exercises and pointed out that it would of course be very nice to give the students very open questions they have to figure out by themselves. This would probably be well received by more interested students but it would be very difficult for less motivated students to finish the lab within 5 hours. This has led to a decrease in more open/demanding questions over the years.

The CC was quite concerned about the spread of questions between exams in terms of the SOLO taxonomy, and told us that he usually favored questions that investigated the students' level of understanding rather than performing a lot of simple computations. At the same time he also had to take into account for that students aiming for the lower grades should be able to pass the exam and that there is always a trade off between these concerns.

Overall the CC was quite pleased with the course in its current state, mainly due to good CEQ ratings. If he would change anything it would be to replace some of the older material/applications with something more modern.

5.5 Limits of the method

The method used in this project has been designed to meet the requirements for the specific task at hand and its limitations in terms of scope and scale. Hence, it has several limitations which need to be pointed out.

First of all, it relies heavily on the SOLO taxonomy and does not provide a full account of other, possibly better, taxonomies. Furthermore, the issue whether or not there is any value to have a course aligned according to the SOLO taxonomy has been disregarded.

Secondly, the method involves a classification done through subjective means. Although several of the authors have been involved in the classification there has at times been disagreements regarding classification, in particulary when deciding between the multistructural and relational levels.

Thirdly, the data used was to a large extent selected based on availability and accessibility. The authors are, however, confident that the availability and accessibility restrictions did not impose additional bias on the data.

Finally, it is worthwhile to point out that the SOLO taxonomy says nothing about the contents of the course. It just describes the level of abstraction required. So in a full course evaluation one should also consider the contents of the course. For example keeping the material modern, as pointed out by the course responsible.

6 Conclusions

Looking at the results, some interesting observations can be noted. First of all, the overall impression is that the course is fairly well aligned in terms of the proportions given to each of the classes in the SOLO taxonomy. Unistructural knowledge comprises around 50 % of the course from the point of view of all investigated areas except for the labs.

In the labs, the unistructural part is close to 70 %. However, this can be explained by noting that the labs contain detailed instructions designed to guide the students through real-world problems. These real-world problems are on the other hand at least relational in character. Furthermore, the labs do provide students with a hands-on experience which could facilitate learning. One possible improvement could be to give the interested student a possibility to solve more open questions. This could be done by starting with open questions and supplying more help to those who need it. Or alternatively, by optional tasks in the laboratory. This approach is somewhat contradicting the historical development described by the course coordinator who pointed out that lab instructions has become more detailed over time due to feedback from lab assistants.

In addition, one can note that there is slightly less relational (and more multistructural) exercises and exam questions compared to what can be found in the course objectives. This is partly be-cause the classification of individual bullet points in the course objectives amounts to 10 % of the total. Moreover, the classification did at times prove to be difficult and could cause some misalignment. Nonetheless, the overall conclusion is that the course is well aligned in terms of the SOLO taxonomy.

What's more, it is noted that a clear escalation in the SOLO taxonomy occurs when studying the exercises. In the start of the course, there are very few relational exercises, whereas they are the dominating type towards the end. Furthermore, there is a transition phase with many multistructural exercises in the middle of the course. This observation point towards that the student is ushered along a clear development trajectory.

When studying the results on exams based on SOLO taxonomy classification it is apparent that students have a lower completion rate for questions with a higher SOLO-level. Although perfectly in accordance with the SOLO taxonomy this was slightly surprising to some of the authors who felt that relational questions often were not necessarily more difficult. Hence, it is worth considering this aspect with some extra attention when designing exam questions in the future.

Summing up, the investigation shows that the studied course can be analysed using the SOLO taxonomy and that it is fairly well aligned. The method could be transferred to other courses as well. Such investigations would be of interest to put this investigation in perspective and is therefore encouraged as future work. It is also interesting to note that the course is well aligned even though the concepts discussed here was not thought of when creating it. It thus seems like thinking about these questions comes quite naturally to experienced course coordinators. This should mean that it should be easy for them to start using it. On the other hand, it would be very beneficial for course coordinators who do not naturally make their courses aligned to think about the concepts.

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