Evaluating Constructive Alignment Theory Implementation in a Power Systems Analysis Course Through Repertory Grids

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***Abstract*—Individuals perceive their environment in terms of their individual mental structures that in turn determine their attitudes toward that environment. This is the focus of personal construct theory (PCT), which states that experiences are meaningful only in relation to the way they are "constructed." Within the higher education system, the "constructs" developed by students determine the way in which they perceive their learning environment and are used to judge or evaluate their learning experiences. To reveal the constructs developed by students, a structured interview methodology known as the repertory grid technique can be used. In this paper, the repertory grid technique is exploited to evaluate a consensus-based constructive alignment theory implementation in a M.Sc.-level power systems analysis course. The repertory grid technique is utilized as an approach to effectively gather feedback from students through interviews during course evaluation meetings. It is shown that the repertory grid technique provides much valuable, insightful quantitative and qualitative data. Experience in using this technique revealed shortcomings that are illustrated and discussed in detail. Various visual and statistical methods are applied to analyze the elicited repertory grids. These analyses, along with the other traditional feedback channels, gave insight into the teaching and learning activities (TLAs) involved in implementing Constructive Alignment Theory in a course and helped determine specific elements of the course design needing improvement for future course deliveries, thus helping to improve education in a cornerstone course of power systems engineering.**

***Index Terms*—Consensus-based course design, constructive alignment theory (CAT), personal construct theory (PCT), power engineering education, power systems analysis, repertory grid, revised two-factor study process questionnaire.**

I. Introduction

A. Context

PERSONAL construct theory (PCT) emerged in 1955 [1] from Kelly's clinical work, which led him to develop the notion that when it comes to personal experience, there is no detached, objective, or otherwise absolute truth. Rather, an experience is meaningful only in relation to the way it has been constructed (views, interpretations, understandings). Within the higher education context, experiences in the teaching and learning process are perceived differently by different parties (e.g., students, teachers, administrators, etc.). These perceptions depend on the "constructs" developed by each party, their internal ideas of the experience that they use to understand their environment. Hence, constructs created by students determine how they perceive their learning environment and are used by them to judge or evaluate their learning experiences.

To reveal the constructs developed by an individual, Kelly created a structured interview methodology known as the repertory grid technique [1]. This technique is built upon PCT [2] and has its basis in the theory that a person's construct is a bipolar[1] perception of events in which he/she identifies two different phenomena as being the same in a specific way and differing from a third. This means that an individual will have a limited number of "constructs" that he/she uses to evaluate the experiences constituting his/her universe. There are many variations of the repertory grid [3]; all of them have in common "constructs" (individual internal ideas to conceptualize the environment) and "elements," those "stimuli" evaluated using the "constructs" developed by the individual.

This technique can be applied to diverse fields; the common focus in all of its applications is to understand or otherwise exploit the use of "personal views." From the clinical and health fields, to areas such as business and IT, the researcher tries to extract and understand the meaning that the experience has for those participating in it. As such, the technique is attractive for its application for course evaluation and quality assessment in the higher education environment [4].

B. Aim and Methodology

This paper presents the application of the repertory grid technique as an evaluation methodology for a 7.5-credit M.Sc.-level power systems analysis course in which constructive alignment theory (CAT) was implemented through a consensus process [5]. This course, "EG2021 Power Systems Part 1," offered by the Electric Power Systems Division of KTH Royal Institute of Technology, Stockholm, Sweden, provides an introduction to electrical power networks and methods for their analysis and serves as the research platform for the work presented here.

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[1]For example, the "construct": good—bad.

According to CAT [6], in an academic environment, the major role in the educational process falls on the students, who use teaching and learning activities to construct their knowledge and achieve desired outcomes. It is thus very important that the course activities should be devised so that students encounter them in an appropriate context, so that they assign a positive value to each of these activities, and see them as a contribution to meeting the course goals and advancing their overall education. Here, the students' perceptions play a key role in the instructor's design of the teaching and learning activities (TLAs). Wood states this assumption[2] in his helpful list of what a teacher should do as "view students' conceptions from their perspectives."

The aim of using the repertory grid technique was to develop a systematic methodology for quality assurance[3] of the implementation of CAT though the consensus-based course design adopted. Hence, different aspects of using this technique to assess the quality of the implementation are discussed, and the authors' own experiences are described. The methodology proposed here is becoming increasingly necessary since students enrolling in power system courses have increasingly diverse backgrounds and with skill levels increasingly inadequate to fulfill the course intended learning outcomes (ILOs) [5].

To perform a repertory grid-based interview, its various phases need to be carefully planned and prepared; the authors describe how this was achieved. In addition, identified shortcomings of the technique are discussed. It is shown that the technique provides much valuable and insightful data that can be analyzed by various methods. Two computer programs were used to analyze the data systematically. The authors' experience reveals that the best outcomes are achieved when the technique is used together with other course evaluation techniques.

C. Contributions

In summary, this paper offers the following three main contributions.

- The combined use of CAT and the repertory grid. Through various descriptive and numerical results, it is demonstrated that the repertory grid is a valuable tool to enhance the implementation of CAT in a higher-level power systems course, and thereby enhance power systems engineering education.
- The combined use of R-SPQ-2F and the repertory grid. The interview participants were not randomly chosen, but selected so as to cover all the different learning approaches. Since the ultimate objective is to reward the deep-approach learners with higher marks, and to encourage the surface-approach learners to shift toward deeper learning strategies, it was crucial to include all the different perspectives on the course. Gathering the "perceptions" of students in different areas will help to improve particular course elements in future course deliveries.
- Identifying, and proposing a solution to, the drawbacks of implementing CAT in the course design. Similarly, the drawbacks of using the repertory grid technique in a power systems course are identified, and solutions proposed.

D. Organization

The remainder of this paper is arranged as follows. In Section II, as background, the concepts of CAT and students' learning approaches are reviewed. This is followed by a brief summary of the implementation of CAT in a power system analysis course through a consensus process. Section III summarizes the theoretical background of the repertory grid technique and describes its application. This includes the design of the repertory grid interviews, their administration, and an introduction to the analysis methods used to interpret the data emerging from these grids. Section IV presents the results from the different numerical methods. In Section V, results from Section IV are used to analyze the impact of different TLAs included in the course design. Examining students' "personal views," so as to understand the perception of the TLAs, allowed suitable modifications to be made to the consensus-based CAT implementation in the course. Finally, Section VI summarizes the findings and contributions of this paper and outlines future studies.

II. Implementation of Constructive Alignment in a Power System Analysis Course

A. CAT and Student Learning Approaches

CAT [6] realizes that there are different student learning approaches, and that the design of TLAs must account for them. This theory classifies students' learning approaches as "surface" or "deep." As the term suggests, the surface learning approach occurs when students focus only on covering the superficial layer of a course's content. The term was coined by Marton and Säljö, who noticed two kinds of responses from students after assessing a reading assignment [7], [8]. The response from those using the surface approach was characterized by a strong focus on memorization of facts and details, without integrating them. Although these students had a recollection of terms and isolated items, they did not show an overall understanding of the underlying ideas conveyed in the reading assignment.

Furthermore, research on the learning approaches of Chinese students has revealed a continuum of student learning approaches, from surface to deep. This research shows that intermediate approaches are constituted by the use of memorization in combination with understanding [9], and bear elements of both surface and deep learning approaches [10].

Several factors trigger a surface, intermediate, or deep learning approach in student learning [6]; a surface approach is triggered by a significant lack of alignment between the ILOs, the TLAs, and the course assessment and grading.

CAT comprises a set of principles that can be used to devise TLAs that help in achieving the ILOs. Carefully aligning TLAs and learning assessment helps to accomplish this. The theory assumes that the students use the activities to construct their knowledge and achieve desired outcomes. Hence, the teacher's role is to design a learning environment that encourages students

[2]T. Wood, "From alternative epistemologies to practice in education: Rethinking what it means to teach and learn," *Constructivism in Education*, Steffe, L. and Gale, J., Eds., Hillsdale, NJ, USA: Erlbaum, 1995, pp. 331–339.

[3]In this context, "quality assurance" is viewed from the students' own perception, hence it is necessary to determine what are the constructs that students use to evaluate the quality of the course in terms of their own experience.

to carry out the TLAs that help them construct their knowledge. This requires a careful alignment of the ILOs by mirroring them in the TLAs that the students undertake under each task.

From a practical perspective, it is not possible to implement CAT so that the course TLAs are fully aligned with the intended learning outcomes. It is thus essential to continuously modify the designed TLAs, to better align them with the ILOs. Since students' perceptions of the course constitute a valuable guide to the modifications necessary, effective feedback channels should be developed to gather the students' own "constructs" of the course.

A comprehensive treatment of CAT is given in [6]; [11] provides an example of the implementation of CAT in a course project in a power system analysis course; and a detailed account of the systematic implementation of CAT in a power system analysis course using a consensus-oriented decision making model is given in [5].

B. Course Design Through a Consensus Process and CAT Implementation

The EG2021 Power Systems Part 1 course was given a complete consensus-based redesign during 2011 to achieve a new format adapted to constructive alignment theory [5].[4] The consensus-based decision-making process involved the adoption of a consensus model, the construction of a design group, and the elaboration of a course design. The *collaborative* consensus model chosen was the consensus-oriented decision-making process (CODM) [12], and the design group comprised M.Sc. and Ph.D. students and faculty. The CODM model was chosen because collaboration was necessary if the final proposal were to have the shared commitment of the group, essential to a successful implementation of the course design.

The CODM model consists of eight steps [5]. An important factor was to change the course assessment to align it to the course ILOs and to provide TLAs supporting the CAT implementation. The new course design included several TLAs to help students adopting the "surface learning approach," as well as those using the "deep learning approach." These changes include the introduction of optional daily in-class exercises, optional weekly assignments, and mandatory weekly tests. Further details are provided in [5].

C. Feedback Channels for Course Evaluation

An important factor in CAT implementation is to continually change the TLAs and learning assessment to align them to the ILOs. To determine the changes necessary, several feedback channels were implemented to gather the students' perceptions of these changes, as compared to the previous course, and to assess the CAT implementation in the course as it progressed.

There were three course evaluations, two between tests and one during the final evaluation. These course evaluations were designed to elicit the students' satisfaction with the current course, as well as gather their ideas on how to modify the course design in a future delivery.

Interview-based evaluations are well known as being very efficient in extracting student feedback and identifying diverse student perceptions. Therefore, in addition to the standard written evaluations, "course evaluation meetings" using the repertory grid structured interview approach were carried out with specific students. This technique is explained in Section III.

The choice of students for the interviews is of the utmost importance, in that they should provide a variety of "personal views" and should have different learning approaches toward the course. Therefore, it is better to choose the students using a deterministic method rather than choosing them randomly. Here, the students were chosen based on their learning approach. Interviews were carried out with students adopting both the surface and deep learning approaches. The students' learning approaches were classified using "the revised two-factor study process questionnaire (R-SPQ-2F)" [1], a brief introduction to which is given below; this questionnaire was included with the final course evaluation.

D. Revised Two-Factor Study Process Questionnaire

During the final course evaluation, the R-SPQ-2F was utilized [13]. R-SPQ-2F is a recognized tool for determining student learning approach. The students respond to each question on a Likert-type scale from 1 to 5. There are two types of questions: those related to the deep learning approach (Type 1), and those related to the surface approach (Type 2). Since the questions are ordered randomly, students are unaware of each question's type, although some of the questions have an obvious "motive." For each student, the scores of each type of question are compiled to give each student's learning approach: The student scoring the highest grade on the Type-1 questions has the deepest approach, while the student scoring highest on Type-2 questions probably has the most surface approach.

Analysis of these results indicates which students have adopted a "surface" or "deep" learning approach; this information can be correlated with student feedback to determine which responses need to be considered in future course deliveries. Furthermore, having identified students with different learning approaches, a careful selection of students can be made for further interviews.

However, it is very hard to frame the R-SPQ-2F questions to conceal the "motives" or "values" behind each question. Some students may attribute a positive or negative value to each question and tailor their answer to manipulate the outcome of the whole questionnaire; that is, they try to appear "deep" when they are in fact operating under a "surface" approach.

This and some other issues result in many students having equal scores for both the deep and surface approach. Since it is not possible to simultaneously have both a deep and a surface approach, this makes the classification of the students quite a challenge.[5] To address this, a new ranking algorithm was developed [5], which determines the student's learning approach and its extent through a single score. Those with a positive score are classified as adopting the deep approach, and the higher the score, the "deeper" the learning approach, and vice versa.

[4]Readers are referred to [5] for additional background on the course, education program, and the consensus-based course design process.

[5]Note that this assumption is necessary when using PCT as a basis of the study.

Using student rankings determined with the new algorithm, deep- and surface-learning-approach students were chosen for the repertory grid interviews reported here.

III. Repertory Grid

A. Background

The repertory grid [14] technique allows the extraction of both quantitative and qualitative information. The repertory grid is a form of structured interview in which a person's perception of a specific topic is captured in the context of his own personal perspective. The repertory grid used here follows a specific design structure in which predefined elements of the interview topic are provided to the participant. Afterwards, the interview elicits the constructs the participant has developed according to his/her own preferences. Using these elicited constructs, each element is rated uniformly

There are various methods for building a repertory grid, with different ways of eliciting constructs or rating the elements. In addition, there are several procedures for analyzing the repertory grid data. The diversity of these methods results in repertory grids of different shape, each suitable for a specific purpose. The ability to perform meticulous analytical analysis on the grids gives the technique much flexibility [14].

Unlike the traditional methods that are "investigator-centered approaches," the repertory grid is a "person-centered approach" [15]: It allows the individual being interviewed to develop constructs using his/her own perception of the subject. This approach has been defined as constructivist assessment [15]. Although there are other methods for constructivist assessment, the repertory grid technique is the one preferred due to its flexibility, which makes it applicable in many different fields such as education [16], IT [17], and information systems [18].

B. Application of the Repertory Grid Technique

As mentioned above, a typical repertory grid is composed of three major components: elements, constructs, and ratings. Each component has its own role in making an efficient repertory grid.

The elements are the fundamental components of a repertory grid. Constructs and ratings are built from them. There are various methods to define elements depending to the research context. Elements can be elicited through an open discussion between the investigator and the subject, or can be supplied to the subject [3], [19]. Nevertheless, elements should be chosen to guarantee proper coverage of the topic under investigation.

For this study, nine elements that had the largest impact on the students' learning approach were identified and were subsequently provided to the students in the repertory grid interview procedure. These elements were the following

1) Lecture slides: The overheads that were used during the course lectures by the lecturer.
2) Course textbook: This course used "Power Systems Analysis" by Haadi Saadat [20]; all the lecture materials and exam question were taken from this book, with additional supplemental notes and handouts provided by the lecturer.
3) Binder: Additional material and notes provided to the students.
4) Final exam: The final examination in the course.
5) Weekly tests: Six weekly tests count for half of the course grade. For each student, the lowest score of the six tests was discarded.
6) Daily exercises: There were daily in-class exercises during each lecture. These exercises were optional and did no contribute to the students' final grade.
7) Luigi's lectures: There were two different lecturers in the course: Luigi and Lennart. This element corresponds to those lectures given by Luigi.
8) Lennart's lectures: This element corresponds to those lectures given by Lennart.
9) Class test solution: After the weekly tests were graded, the teaching assistants stayed with any interested students to solve the test's problems using the blackboard.

With these elements, the next step is to elicit the constructs of the grid. The constructs are the qualities that carry the subject's perception of the elements [21]. Generally, there are four major methods of generating the constructs for the grid [19]. The classical method is eliciting them from triads: Three elements are provided to the subject, then he/she is asked how one of these three elements differs from the other two, and to determine the two elements that are similar to each other. The response to this question is needed to derive the contrast poles for each construct. Later, the subject will be asked to link each element to one of these contrast poles using a specific rating method.

Another method of generating constructs is to elicit them from dyads [22]. This method is useful whenever the subject finds the triads method complex. The procedure is to select two elements and ask the subject if they are similar or different. The subject's response then can be used for eliciting the constructs.

In this study, eight students participated in 1-h interviews. According to [18], a sample size of more than 25 will not provide any new information. That means that about 33% of the students had to be interviewed. However, only eight (out of 72, 11%) interviews were carried out because few students chose to cooperate with this part of the study. The students were selected using the new ranking method described in Section II. A total of 59 students participated in R-SPQ-2F, and each was assigned a rank from 1 to 59, with the student with rank 59 expected to be the one with the deepest learning approach. The eight students who participated in the repertory grid had the ranks: 6, 19, 29, 41, 43, 48, 52, and 57. As can be observed, they were chosen to range across both learning approaches.

The strategies used for eliciting constructs during the interviews resulted in a combination of triads and dyads. The researcher was actively involved in the interview and made notes of the elicited constructs during the interview. The students were interviewed in four sessions; each session was carried out with two students. The triads that were used in these interviews were the following:

- Elements 1–3;
- Elements 4–6;
- Elements 7–9.

For some students, dyads were also used:

- Elements 2 and 3;
- Elements 5 and 6;
- Elements 8 and 9;

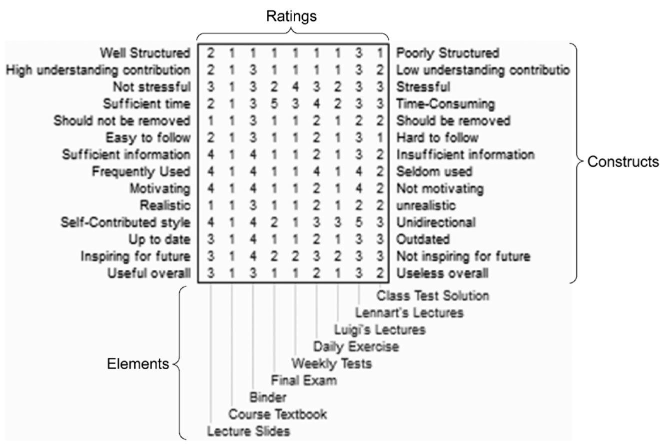

Fig. 1. Sample repertory grid.

- Elements 7 and 8;
- Elements 4 and 6;
- Elements 4 and 5;
- Elements 7 and 9.

In addition, the students were asked to give their perceptions of all elements. At times, these suggestions were themselves used to elicit the constructs. Therefore, each interview resulted in several elicited constructs for each student. It was decided in advance that the students would not rate the elements during the interview. Instead, they were e-mailed the elicited constructs in the form of MS Excel sheets after all the interviews were carried out. This gave the students enough time to think about their ratings, and gave the researcher time to present the grids in a form readily understandable by the students.

Scrutinizing the constructs for each student, some constructs were found not to be applicable to all elements. Although this phenomenon is quite usual for any repertory grid, it is problematic when attempting to carry out further mathematical analysis of the grids. In addition, several constructs that came from different students were similar or exactly the same. For example, the construct "frequently used—seldom used" was repeated for almost all students.

It is important for quality assurance to be able to compare different grids; this implies that the grids must have similar constructs. Hence, it was decided to select the most relevant and frequent constructs from all elicited constructs. These selected constructs were then provided to all students together with one additional construct "overall useful—overall useless," with a total of 14 constructs. The additional construct enables specific data analysis illustrated later.

The fundamental assumption of this approach for selecting elements and constructs is that the rating of the elicited constructs reflects the individual's personal perception of the element [14], [23]. Fig. 1 shows a sample of the prepared repertory grid of one of the students.

Ratings act as specific links between constructs and elements. There are several methods of how to establish this link [3], [19]. Dichotomizing provides a two-point scale in which the subject is asked to choose if the element is closest to a left or right pole. Another procedure is to rate each element using the Likert scale. It can be done either using a seven-point scale, or a five-point scale like that used for this study. Also, a rating method can be used in which the subject is asked to rate the elements for each construct. Each of these methods is suitable for a specific purpose, and all have their advantages and disadvantages [3].

As mentioned before, the students in this study were asked to apply the rating method using a 5-point Likert scale. A rating of 1 means that the corresponding element is closest to the left pole, while 5 means that it is closest to the right pole. The application of rating methods provided the possibility of performing mathematical analysis.

C. Data Analysis

Once each student rates the repertory grid, several descriptive and mathematical analyses can be carried out. The computation burden of these analyses depends on the size of the grid, as well as the applied rating method. Kelly developed a specific nonparametric factor analysis that was simple enough to be carried out by hand [1]. He used the dichotomous scoring method for his repertory grids, but as different rating methods emerged, the analysis of repertory grids required more complex mathematical methods.

For this study, three different analyses were carried out for the grids. First, Principal Component Analysis (PCA) was performed. PCA is a powerful statistical method used to find interactions between data. Eigenvectors (components) of a set of data are found so that the projection of data in their corresponding direction results in a maximum variance. Then, these components form the axis of a specific coordinate, in which the constructs and the elements with the greatest variance are linked to them [15].

Next, "cluster analysis" was carried out for each grid. Cluster analysis reorders both elements and constructs in the form of a tree; those objects that are similar are placed in branches next to each other. In addition, it may be necessary to reverse some constructs so as to make the tree pattern homogenous. Finally, a descriptive analysis is conducted by interpreting the mean of the rating of the grid's objects.

Today, several computer programs that can be used to build, prepare, and analyze a repertory grid have made the process of complex analysis more straightforward. In addition, they provide visual aids that make the grid interpretation easier. Idiogrid and Rep IV [24], [25] were the computer programs used in this study. Rep IV was used for the visualization of the prepared grids, as for the example shown in Fig. 1. Idiogrid provides access to various mathematical analysis and cluster analysis tools. For the purpose of this study, Idiogrid was used to perform PCA and to calculate the mean of the ratings for the grids.

IV. Results

Eight repertory grids were analyzed for the eight students who participated in the interviews. All eight grids cannot be shown here, due to space limitations, but this section reports relevant results from these analyses that cover the most important findings. The grids, created using the Rep IV software (see Fig. 1), have nine elements and 14 constructs each. The Likert 5-point rating scale was applied to link elements with constructs.

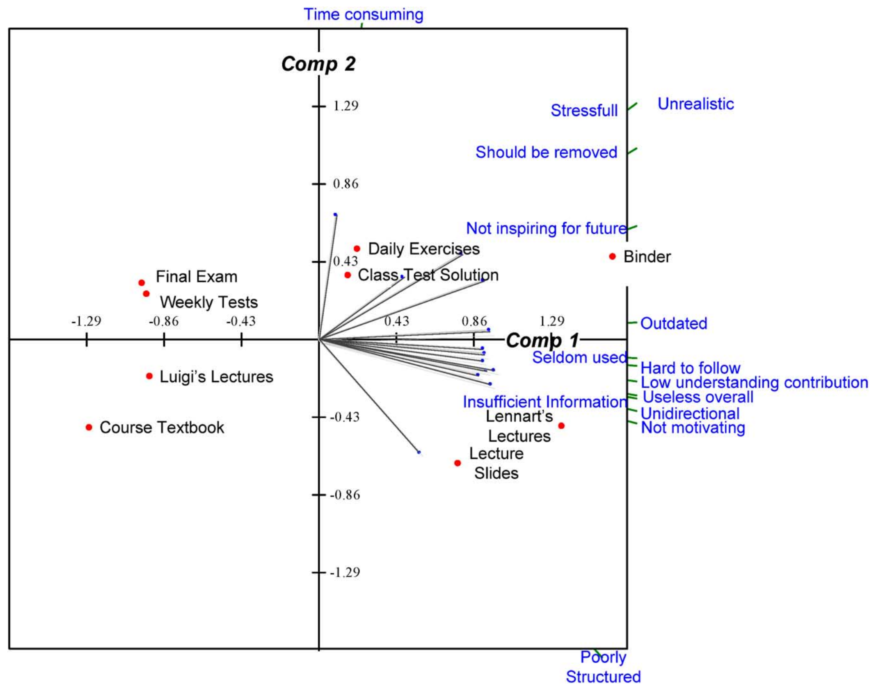

Fig. 2. PCA for the grid in Fig. 1.

A. Principal Components Analysis

PCA was performed using the Idiogrid ver. 2.4. [25] and applied to extract the first two components. Observe that the first two components normally account for most of the data, while additional components may account for up to 30% of the data [19]. However, usually this value is less than 10%. As an example, the results of PCA analysis for the grid of Fig. 1 are shown in Fig. 2.

To interpret the plot, note that the construct shown corresponds to the right poles. The left pole can be considered to occur on the opposite side of the plot, as the constructs are bipolar. In addition, those elements given more extreme ratings appear nearest to the boundaries of the plot.

In Fig. 2, the position of the elements and constructs is a good representation of their correlation. For example, this student believes that the elements "daily exercise" and "class test solution" are similar in the case that both are stressful and should be removed from the course design. Note that these analyses add no new data to the repertory grid, but simply help in the interpretation of the grids rated by the students.

A drawback with the repertory grid technique, common among many other written evaluations, is that if any student fills in the rating using a fixed pattern, this can be detected, and the feedback from that student must be disregarded. Although the students were given enough time and were asked to fill in the ratings carefully, one of them actually filled in the grid as shown in Fig. 3.

As can be observed from Fig. 3, the student gave the same rating for most of the elements for each construct. This makes the repertory grid and its subsequent analysis useless. Although the students were given enough information about the repertory grid technique, they probably they had no idea of how the information in the grid was going to be analyzed. Therefore, they did not realize that if they entered the ratings carelessly, this could easily be detected. No useful information can be extracted from the PCA analysis of such a grid, and thus there is no surprise that the Idiogrid software gives an error when it tries to calculate the PCA for that grid. Therefore, this student's repertory grid was eliminated in further analyses.

	Lecture Slides	Course Textbook	Binder	Final Exam	Weekly Tests	Daily Exercise	Luigi's Lectures	Lennart's Lectures	Class Test Solution	
Well Structured	1	1	1	1	3	1	1	1	1	Poorly Structured
High understanding contributio	1	1	1	1	1	1	1	1	1	Low understanding contribution
Not stressful	1	1	1	1	1	1	1	1	1	Stressful
Sufficient time	1	1	1	1	1	1	1	1	1	Time-Consuming
Should not be removed	1	1	1	1	1	1	1	1	1	Should be removed
Easy to follow	1	1	1	1	1	1	1	1	1	Hard to follow
Sufficient information	1	1	1	1	1	1	1	1	1	Insufficient information
Frequently Used	1	1	1	1	1	1	1	1	1	Seldom used
Motivating	1	1	1	1	1	1	1	1	1	Not motivating
Realistic	1	1	1	1	1	1	1	1	1	Unrealistic
Self-Contributed style	3	3	3	3	3	3	3	3	3	Unidirectional
Up to date	1	1	1	1	1	1	1	1	1	Outdated
Inspiring for future	2	2	2	2	2	2	2	2	2	Not inspiring for future
Useful overall	1	1	1	1	1	1	1	1	1	Overally useless

Fig. 3. Example of repertory grid filled in with fixed patterns.

B. Cluster Analysis

The cluster analysis in this study was carried out using the Rep IV program. Another student's repertory grid, prior to cluster analysis, is shown in Fig. 4.

The result of the cluster analysis for Fig. 4 is shown in Fig. 5. As mentioned before, cluster analysis will reorder both elements and constructs. For example, it can be observed that in the first level, there are twin branches of "course textbook—lecture slides," "Lennart's lectures—Luigi's lectures,"

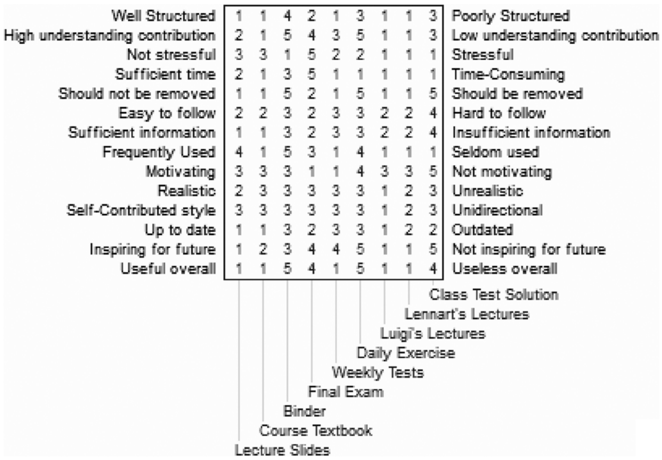

Fig. 4. Repertory grid used for cluster analysis.

and "binder—daily exercises." This is quite logical as these elements share common characteristics. Cluster analysis reveals those elements and constructs that are in tight correlation; this will be valuable in modifying the course. For example, this student believes that constructs of "time consuming—stressful" are in the same group. Other feedback or PCA analysis can be scrutinized to identify those elements that this student sees as stressful. Then, a decision can be made as to whether to modify the timing of those elements.

Furthermore, elements that are classified next to each other can be further scrutinized to identify similarities, again to help to identify elements that need to be modified.

C. *Descriptive Analysis*

Descriptive analysis is carried out on factors not amenable to analysis using visual aids. In this study, the mean and mode of the elements were calculated for each grid, using the Idiogrid software. As the grids have identical features (but not ratings), a group of grids can be chosen and used to form a new grid using the elements' mean or mode. For example, the result of the analysis for the grid of Fig. 5 is shown in Table I.

The mean and mode for each element give a general overview of the students' opinion about that element. For example, this student probably believes that Luigi's lectures were the most valuable part of the course, while the binder and the daily exercises are the least useful elements. Then, further descriptive feedback from the student can be analyzed to discover why he/she has such a perception; the student's suggestion to further improve the daily exercises or binder can then be examined further.

As the elements and constructs are the same for all grids, the mean and mode of each element can be calculated in total. The results are shown in Table II.

V. Discussion

The results obtained for each element of different grids are discussed here. Possible modifications to the course design are suggested either from student descriptive feedback or the authors' analyses. As mentioned before, nine elements form the major components of the course structure; their modification will directly affect the course structure and its possible outcomes.

The elements are discussed in three different groups. Course materials include the course textbook, lecture slides, and the binder. Course lectures include Luigi's lectures, Lennart's lectures, and the class test solution. Finally, course exams include the final exam, weekly tests, and daily exercises.

Please note that the discussion provided here is not a final conclusion on the course and its potential modifications, but simply serves as an analysis of the results obtained from the elicited repertory grids.

A. *Course Material*

The results show a good degree of satisfaction with the course main textbook. PCA analysis shows that the constructs "inspiring for the future" and "up to date" are the most frequent for the textbook, and it has the lowest mean (1.46) of all the other elements.

This can be contrasted with the course binder. The constructs "useless overall," "out of date," "low understanding contribution," "seldom used," and "should be removed" are all correlated with this element, and the mean rating is also high (2.94). All these data show a low satisfaction level. The students prefer to focus on just one source of information for the course instead of having alternative or extra compendiums. Most of them reported using the binder quite rarely: They trusted a textbook of high international standard more than a compendium.

For the lecture slides, there were two main perceptions, stemming from the fact that the information on the slides is covered in the course textbook. Some students believe that this decreased their motivation for attending the class; others believe that this made following the lectures quite easy and reduced stress during class.

B. *Course Lectures*

From the cluster analysis, most of the students classify the two lecturers with the same constructs, and the ratings indicate an acceptable level of satisfaction with both teachers. Most of the students linked Luigi's lectures with the construct of "inspiring for the future," while "self-contributed style" is the most frequent positive construct for Lennart's lectures. However, most of the students suggested that the lecturers should not just rely on overheads, but should sometimes use the blackboard during class. This could be one reason that some students also linked these elements with constructs such as "hard to follow" or "poorly structured."

The class test solution results show strong dissatisfaction among the students. Most of them seldom used the class test solution. They believe it is "not motivating" and "useless overall." They have also frequently linked "insufficient information" with this element.

C. *Course Exams*

Weekly tests are quite popular among the students. Almost all of them believe that weekly tests helped them a lot during the course. The results show "useful overall" as a frequent construct for weekly tests. This element is always linked with the right

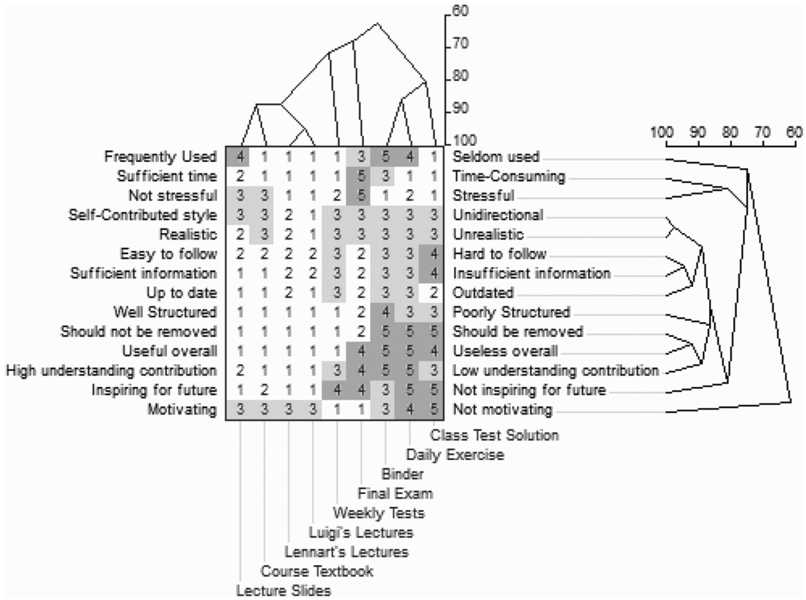

Fig. 5. Cluster analysis of Fig. 4.

TABLE I
ELEMENTS' MEAN AND MODE FOR GRID OF FIG. 5

Element	Mean	Mode
Lecture slides	1.93	1
Course textbook	1.71	1
Binder	3.50	3
Final exam	3.00	2
Weekly tests	2.14	3
Daily exercises	3.50	3
Luigi's lectures	1.29	1
Lennart's lectures	1.5	1
Class test solution	3.14	3

TABLE II
ELEMENTS' MEAN AND MODE FOR ALL THE GRIDS

Element	Mean	Mode
Lecture slides	2.38	1
Course textbook	1.46	1
Binder	2.94	3
Final exam	2.95	1
Weekly tests	1.81	1
Daily exercises	2.65	3
Luigi's lectures	1.91	1
Lennart's lectures	2.20	1
Class test solution	2.58	3

pole of the constructs of the grid. The students believe that the weekly tests are motivating and allow them to follow the course more effectively. This reduces their stress related to the final examination and keeps them prepared.

In the case of the final examination, no persistent pattern was found between the elements and the constructs. One reason could be that most of the constructs are not directly applicable to this element. Cluster analysis also shows no clear pattern, and most of the time this element does not share common roots with any other element in the first level of the cluster tree. This is not a big issue in this case, as there are other evaluations available to extract information about this element. In addition, the students who participated in repertory grid interviews were asked to give specific comments and suggestions about each element.

In general, this is a drawback of the repertory grid technique: It is not straightforward to elicit the constructs so as to be perfectly applicable to all elements. Therefore, for course evaluation purposes, the repertory grid has its best outcome when it is used in parallel with other evaluation methods.

The result of cluster analysis shows that the daily exercise shares a common first-level root with the class test solution most of the time. This is due to the fact that the students are not quite satisfied with these elements. They think that this element is "stressful," "poorly structured," and "useless overall." The students' suggestions indicate that it is not a good idea to devote a part of the class time to daily exercises, with most of them seeing that as a useless effort. Actually, this is quite surprising, as daily in-class exercises seemed to be a very good way to support CAT. Further analysis should be carried out to determine why this element did not have the desired impact.

It is worth mentioning that the students' participation in daily class exercises was continuously monitored during the course. This revealed a correlation between the students' final grade, learning approach, and participation in daily class exercises. Although these correlations are beyond the scope of this paper, it is evidence that daily exercises are not completely useless (as the repertory grid results suggests)—this has been addressed by the authors in another study, to be published separately. One possible explanation could be the lack of student motivation. As the daily exercises were optional, the students did not need to participate. This affected their perception of the element, with most of them regarding it as a useless effort.

VI. CONCLUSION

This paper described an application of the repertory grid technique to evaluate the constructive alignment theory implementation in a M.Sc.-level power systems analysis course. The fact that an individual's perception of different course elements can be measured makes a repertory grid a suitable option for assessing the value of different teaching and learning activities. Specifically, the repertory grid technique is a satisfactory evaluation approach for higher education courses where constructive alignment theory is used to design the course. To enable a meta-cognitive understanding environment, it is crucial to evaluate student perception, to improve the activities accordingly, and to implement these improvements in the next course delivery. For this, the efficiency of the feedback channels plays a key role.

Through various analyses, it is shown that repertory grid is an effective evaluation method. Once the grids are elicited, it is possible to carry on a variety of analyses that provide qualitative, quantitative, and visual results. These results enable the instructor to use them for further modifications in the course.

The methodology presented allowed the elements that need modifications in future deliveries of this course to be clearly highlighted. In particular, in the subsequent delivery of the EG2021 Power Systems Part 1 course, the following modifications were made to the elements.

- Eliminated and replaced by another TLA: Elements 3 (Binder), 6 (Daily Exercises), and 9 (Class Test Solution) for which the repertory grid analyses showed a correlation with the constructs "Not Inspiring," "Useless overall," "Should be replaced" (see Fig. 5).
- Major modifications: Element 5 (Weekly Tests), which showed a slight correlation with the construct "stressful." The number of tests was reduced to four (from six), and only the three highest grades were counted.
- Improvements: Elements 7 (Luigi's lectures) and 8 (Lennart's lectures). In particular, element 8 was modified drastically as PCA (see Fig. 2) revealed poor structure.

The element "Final Exam" proved difficult to analyze using repertory grids; this is an issue related to the elicitation of constructs.

This paper highlights the importance of the elicited constructs. Allowing students to elicit and rank their own construct for each element helps to reflect their own perception of that element. This procedure gives the opportunity to shed light on hidden aspects of the students' insight or opinion and find their unique perception of the course. For some elements, the students have a unidirectional interaction, and the elicited constructs may not be applicable to all the elements. This will affect the final analyses of results and their interpretation, as shown by there being no concrete pattern for the element "final exam."

For student course evaluation purposes, the combined application of repertory grid and other evaluation methods can provide the best result. For example, those elements that show lower correlation with the elicited constructs, or those parts of the course that the students are less involved with, can be evaluated using traditional methods. Then, the final results can be compared, or be used solely to further modify the course in future deliveries. If the results are consistent, modifications can be applied to the course design. However, should they be contradictory, further investigation may be needed. The authors recommend the use of standard written evaluations, as carried out in this study.

Future work may include an innovative method to combine the data analysis using the repertory grid technique with the results from traditional evaluation methods, and to investigate the correlations and contradictions. In addition, the applied modifications can be later investigated to determine if they are aligned with the course ILOs, and if they have an effect in the students' satisfaction level and performance.

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