The Use of Decision-Making Methods to Ensure Assessment Validity

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***Abstract*— In this paper, we present the problem of ensuring a course assessment's validity from the pedagogical and decision-making perspective. The assessment's validity is one of the five criteria considered in the Van der Vleuten utility formula. It is vital to improve the validity of the whole course by clearly linking the assessment plan to the intended learning outcomes (LOs). The first step is to identify the criteria by which learning outcomes will be evaluated. We used a focus group to identify the following four criteria: importance of the topic or context for the future profession; required level of the LO based on chosen taxonomy; contribution to the development of the 21st-century generic skills and student workload needed to fulfill the LOs. In the second phase, we used the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) to determine the weights of evaluation criteria and the consequent relative importance of LOs of a course we used as a case study. The problem is interesting from the decision-making point of view as well because we consider prioritization (not selection) of alternatives (here LOs), and alternatives (LOs) as not independent of each other.**

Keywords—assessment, assessment validity, AHP, ANP

I. INTRODUCTION

The Fourth Industrial Revolution impacts higher education significantly fostering questions about how universities should deliver their curricula to fulfill the multiple requirements. Universities should find a model that delivers the knowledge and skills required to support independent learning and lifelong learning, especially in the rapidly changing engineering and technology management fields, while also satisfying their academic mission. All these requirements must be met within the study program and course learning outcomes. This paper introduces multicriteria decision-making methods to ensure that the assessment of student achievements is aligned with learning outcomes, valid and reliable. On the other hand, it is also an opportunity to show that methods originating from engineering and technology management, which encompass multicriteria decision-making methods, can help education science. The research conceptual model is presented in Figure 1. In order to ensure the optimal technology and engineering management, effective teaching and inquiry-based learning are required. Each learning outcome encompasses cognitive level based on taxonomy (i.e., Bloom taxonomy), the content of learning based on requirements coming from the employers (i.e., in the field of engineering and technology management) and academic mission, as well as the assessment task that assesses if students grasped knowledge and skills on the desired level. Finally, to ensure the assessment validity, we introduced multicriteria decision-making methods (hierarchical and network-based) to estimate the intended learning outcomes' weights.

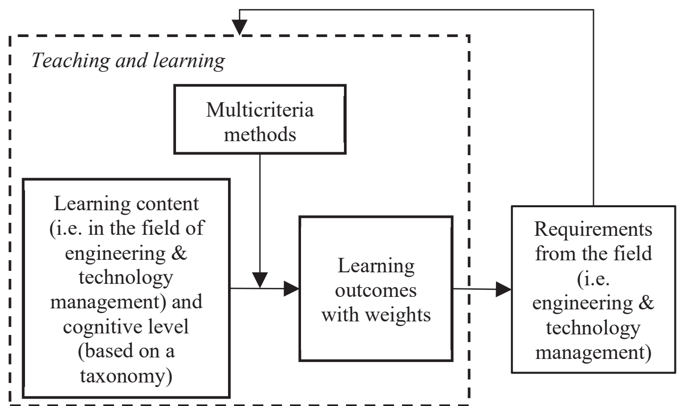

Fig. 1. Conceptual model of the presented research

Construction and implementation of appropriate assessment tasks is an important exercise at the course level regardless of the mode of course and study program delivery (face-to-face, hybrid, or online). There are many approaches on how to create these tasks and which evaluations to use to evaluate assessment appropriateness. In most research, validity, transparency, and reliability are the main assessment quality criteria [1].

Some researchers advocate a holistic approach that considers the whole assessment plan with a carefully prepared set of assessment tasks at the course level and needs that assessment plan to be evaluated according to an overarching framework. According to [2], the utility formula (framework) of assessment depends on five factors: reliability, validity, educational impact, acceptability, and the costs of assessment. There are other utility models for assessment [3] based on the Van der Vleuten model. We must be aware that the balance should be found at the course level and not on the single assessment task. Any single assessment method can never be perfect on all criteria, and the assessment involves a compromise. The first and necessary condition for building an appropriate assessment plan is ensuring the assessment set's validity. The precondition is that course learning outcomes are constructed correctly using a taxonomy of learning outcomes and related to the study program learning outcomes. In most cases, cognitive dimensions following Bloom's taxonomy might be considered.

To ensure the assessment's validity, the first step in preparing an assessment plan is determining the relative weights (importance) of the course learning outcomes (LOs). The relative importance of the course LOs can be determined by group decision making using the analytic hierarchy process (AHP) [4] or by the analytic network process (ANP). Participants for the group-decision making should be selected carefully. An example of discrete mathematics with graph theory (DMGT) will be presented [5].

The second step is the constructive alignment of LOs with assessment tasks and teaching and learning activities [6]. It is important to construct formative assessment tasks that support summative tasks to ensure timely and useful feedback to students [7]. The linkage between formative and summative assessment tasks is essential for timely feedback to students and an adjustment of teaching and learning methods.

The third step is the evaluation of the full assessment set against the utility formula. For each assessment set, the factors' relative importance can be determined by AHP-based group decision making. An example of the DMGT course will be presented. Finally, an analysis of course practices and recommendations for improvement follows.

II. HIERARCHICAL AND NETWORK APPROACHES

In the research described in this paper, we used several decision-making methods. Therefore, in this chapter, we introduce them briefly. AHP and ANP are well-known multicriteria decision-making methods used for selections or prioritizations. In our case, they are applied for the prioritization of learning outcomes through two decision models. The elements of the decision model are goals, criteria, and alternatives (here learning outcomes). The AHP model is hierarchical, i.e., it does not consider dependencies between the model elements. The ANP is the network model, i.e., it considers dependencies between the elements in the model. In most network models, there are dependencies among the criteria, and among criteria and the alternatives, but not among the alternatives. In our case, since learning outcomes can influence each other, the model will contain connections between the alternatives.

There are several steps in implementing the AHP [8]:

- The first step is the creation of the hierarchical structure of the decision-making problem. The structure in the form of a hierarchy consists of a decision-making goal at the top of the hierarchy, criteria at the second level of the hierarchy, and alternatives at the last level of the hierarchy. Criteria can be decomposed into sub-criteria and, deeply, to even more sublevels if needed. When creating the hierarchy, many approaches can be used. Some of them are explained in [9].
- The next step is making pairwise comparisons of hierarchy elements with respect to elements of higher levels. Here, Saaty's scale is used. Respondents must pay attention to consistency in making judgments. Consistency is related to respecting the transitivity concept on a Saaty's scale.
- When the pairwise comparisons tables are created by individuals, they must then be aggregated using the geometric mean, and further priorities can be calculated. Several approaches can be used here. Also, there is various software that supports the calculation of priorities.
- The last step is conducting the sensitivity analysis and making the final decision. In the sensitivity analysis, we analyze how changes in criteria weights influence the final decision.

Steps necessary to be taken when using the ANP method [10] are as follows:

- The first step is to create a network model of the decision-making problem. The network model is used when there are dependencies and feedback in the problem. In many cases, decision-making criteria are not independent (which is an assumption of a hierarchy), but elements of a problem can influence each other. Elements are grouped in clusters. Decision-making problems can be presented graphically at element (node) and cluster levels.
- When a network is created, we create a zero-one square matrix that describes the connections between a network's elements. Also, we create a zero-one square matrix on the cluster level.
- The next step is to create an unweighted supermatrix, i.e., zero-one square matrix in which elements are replaced with local priorities of elements. To calculate the local priorities of elements, we need to conduct pairwise comparisons of all elements from the same clusters with respect to superior elements.
- The following step is to calculate the matrix of weights of clusters. The weights of clusters are calculated using the pairwise comparisons procedures of clusters with respect to superior clusters.
- After the unweighted supermatrix and matrix of weights of clusters are obtained, we calculate the weighted matrix by multiplying the unweighted supermatrix cells with weights of clusters.
- Finally, we calculate the limit supermatrix by multiplying the unweighted supermatrix by itself until it converges. Then, we can identify the final priorities of elements from any column of the limit supermatrix.

III. CASE STUDY: DISCRETE MATHEMATICS WITH GRAPH THEORY (DMGT)

A. Context of the case study course DMGT

The course Discrete Mathematics with Graph Theory (DMGT) is taught on the graduate (master) level, and due to the European Qualification Framework (EQF) as well as to Croatian Qualification Framework, the level of the course learning outcomes should be predominantly on the level Apply, Analyze, Evaluate and Create according to the revised Bloom's taxonomy of cognitive process dimension [11].

Teachers put special effort into constructive alignment for the course DMGT and relate learning outcomes with teaching and assessment methods [5]. The term constructive alignment is coined by John Biggs. In short, it means learning outcomes must be aligned with teaching, learning, and assessment as well [6].

The DMGT course is divided into two parts, as the title suggests: discrete mathematics and graph theory. Nevertheless, both parts are abstract and complex, and at the same time, they should be applicable because students study IT, not mathematics. The course's goals are reflected in the six learning outcomes that cover mathematical theory and applicability. A course LOs in general are not independent of each other, and some outcomes precede others. In Table I. LOs of the DMGT are given, and for each LO, its predecessors are listed.

TABLE I. LEARNING OUTCOMES OF DMGT WITH PREDECESSORS

Learning outcome	Predecessors
LO1. Identify structure and type of proofs in mathematics	-
LO2. Define and classify binary relations on sets, knowing their properties and characteristic examples	-
LO3. Apply theory and algorithms based on number theory to problems from cryptography	LO1, LO2
LO4. Define and connect fundamental notions and problems in the scope of graph theory	LO2
LO5. Effectively work in a team on problem posing and solving real problems related to graph theory and discrete mathematics	LO3, LO6
LO6. Apply theorems and algorithms from graph theory to standard exercises from graph theory	LO1, LO4

Some LOs are predominantly abstract and "purely" mathematical (LO1, LO2, LO4, and LO6). Their positioning on revised Bloom's taxonomy of the cognitive process dimension is divided between understanding and analyzing. For example, LO6 is a common learning outcome for mathematics where students are supposed to apply what they learn to the standard set of exercises. Finally, LO3 and LO5 are difficult because students are expected to interpret what they learned in mathematics, connect it to knowledge and skills from other courses, and develop problem-posing and problem-solving skills essential for their professional life. Additionally, problem-solving is an essential civic generic skill. To confirm the achievement of these two LOs, students need to create a solution, peer-assess, and self-assess solutions that prepared their teams and other teams.

As mentioned earlier, teachers align the course learning outcomes with teaching and assessment methods [5], but for more precise confirmation of validity, decision-making methods are required. In other words, assessment tasks should be weighted (related to percentages or points) based on their contribution to the learning outcomes. However, for that purpose, it is necessary to accompany learning outcomes with weights and then relate learning outcomes to assessment tasks and distribute weights among them. It leaves us with an assignment to determine the weights of course learning outcomes. We use several multicriteria decision-making methods to perform it, but all of them include criteria for evaluating the importance of learning outcomes.

B. Criteria for evaluation of learning outcomes

Criteria identification for LO evaluation was based on two rounds of focus group discussion. There were six group members involved, and all members were teachers and researchers within the interdisciplinary field of decision-making theory and practice. In the first round, the group members list possible criteria, and seven criteria were collected. Then, the list of criteria was distributed to all focus group members for consideration and comment. In the second round, the final list was identified, and each criterion was equipped with a short description. The final list is as follows.

- C1 - Importance of the topic or context for the future profession (alignment of the LO with the study program LOs)
- C2 – Required level of the LO based on Bloom's taxonomy (other taxonomy can be used if relevant for the course)
- C3 - Contribution to the development of the 21st-century generic skills (generic skills that are necessary for successful professional and civic life in the 21st century, such as critical thinking, problem-solving, digital skills, informed decision making, creativity, and innovation)
- C4 - Student workload needed to fulfill the LO (demanding for students taking into account their prior knowledge and workload they need to invest in the course)

It was evident that criteria are not equally important and that they are not independent of each other. Therefore, it is necessary to equip them with relative importance within a given study program context and treat them as dependent.

C. Prioritization of LOs at course DMGT using the hierarchical model

Figure 2 presents a hierarchical model used for the prioritization of learning outcomes at course DGMT. At the top of the model is decision-making goal (g): to determine the distribution of points at the course on learning outcomes. At the second level, there are criteria for evaluating learning outcomes. Finally, at the third (and last) level, there are learning outcomes. As stated earlier, modeling using the hierarchy does not include dependencies between the criteria and the learning outcomes.

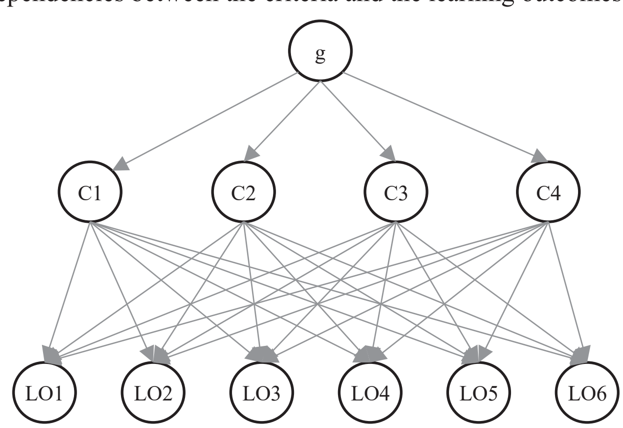

Fig. 2. Hierarchical model

TABLE II. CRITERIA WEIGHTS

	C1	C2	C3	C4	Weights	CR
C1 - Importance of the topic for the profession	1	1,74	2,05	2,93	0,4164	0,0041
C2 - Required level of the LO based on Bloom's taxonomy	0,57	1	0,94	1,89	0,2311	
C3 - Contribution to development of the 21st century generic skills	0,49	1,06	1	1,93	0,2229	
C4 - Student workload needed to fulfill the LO	0,34	0,53	0,52	1	0,1297	

TABLE III. PRIORITIES OF LOS

	C1 0,42	C2 0,23	C3 0,22	C4 0,13	Total priorities
LO1 - Identify structures and types of proofs in mathematics	0,08	0,24	0,13	0,22	**0,15**
LO2 - Identify and classify binary relations on sets, knowing their properties and characteristic examples	0,13	0,17	0,11	0,13	**0,14**
LO3 - Apply theory and algorithms based on number theory to problems from cryptography	0,19	0,16	0,18	0,17	**0,18**
LO4 - Define and connect fundamental notions and problems in the scope of graph theory	0,16	0,11	0,14	0,11	**0,14**
LO5 - Effectively work in a team on problem posing and solving real problems related to graph theory and discrete mathematics	0,28	0,18	0,29	0,22	**0,25**
LO6 - Apply theorems and algorithms from graph theory to standard exercises from graph theory	0,15	0,14	0,15	0,14	**0,15**

In determining weights of the four criteria, group decision making was conducted with five teachers (two assistant professors and three professors). The results are presented in Table II. The table contains group judgments, criteria weights, and size of consistency ratio. The most important criterion is C1, then there are C2 and C3 as almost equally important, and the last is C4.

After the criteria weights were calculated, pairwise comparisons of the alternatives (LOs) per each criterion were given by four teachers at the course DMTG (lecturer, two assistant professors, and a full professor). The cumulative results are given in Table III.

D. Prioritization of learning outcomes to course DMGT using the network model

The network model of the decision-making problem for prioritization of learning outcomes to course DMTG is presented in Figure 3. The left part of the figure contains a presentation of the problem at the element (node) level, and the right part of the figure presents a network-level presentation of the problem. The connections between the structure's elements were identified through several focus groups that included participants mentioned earlier.

The obtained networked model is more specific than many ANP models from the literature. The specificity is the existence of connections between the alternatives, i.e., LOs as a consequence of predecessors given in Table I. This is not a typical decision-making problem that contains criteria and alternatives and where a goal is to select the best alternative. Here we talk about prioritization (no selection), and additionally, there are relations between the alternatives. Some learning outcomes should "precede" other learning outcomes (i.e., "other" learning outcomes require that some learning outcomes are already adopted—learned).

Consequently, the question of how to model relations between the learning outcomes appeared. In our case study, if LO1 precedes LO2, we modeled it as LO1, depending on LO2 in the ANP model. If LO1 precedes LO2, LO2 is a more complex goal. Additionally, LO1 may only exist because it is needed to adopt LO2, which means that LO2 influences LO1.

The unweighted supermatrix of the problem is given in Table IV. The matrix of weights of clusters is given in Table V. Finally, the learning outcomes' total priorities are taken from the limit supermatrix and are presented in the last row of Table VI.

TABLE IV. UNWEIGHTED SUPERMATRIX

	goal	C1	C2	C3	C4	LO1	LO2	LO3	LO4	LO5	LO6
goal	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C1	0,42	0,00	0,00	0,00	0,00	0,25	0,25	0,25	0,50	0,40	0,25
C2	0,23	0,40	0,00	0,70	0,70	0,25	0,25	0,25	0,17	0,10	0,25
C3	0,22	0,60	0,00	0,00	0,30	0,25	0,25	0,25	0,17	0,40	0,25
C4	0,13	0,00	0,00	0,30	0,00	0,25	0,25	0,25	0,17	0,10	0,25
LO1	0,00	0,08	0,24	0,13	0,22	0,00	0,00	0,00	0,00	0,00	0,00
LO2	0,00	0,13	0,17	0,11	0,13	0,00	0,00	0,00	0,00	0,00	0,00
LO3	0,00	0,19	0,16	0,18	0,17	0,50	0,50	0,00	0,00	0,00	0,00
LO4	0,00	0,16	0,11	0,14	0,11	0,00	0,50	0,00	0,00	0,00	0,00
LO5	0,00	0,28	0,18	0,29	0,22	0,00	0,00	0,50	0,00	0,00	0,50
LO6	0,00	0,15	0,14	0,15	0,14	0,50	0,00	0,00	0,50	0,00	0,00

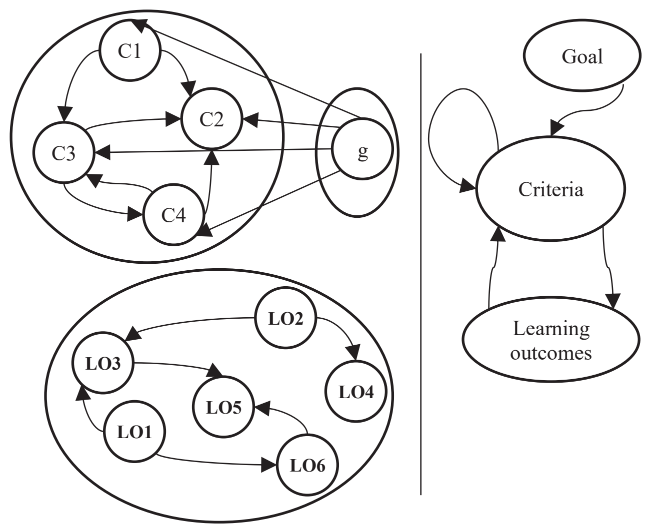

Fig. 3. Network model: node level (left) and cluster level (right) (due to image clarity, feedback between criteria and learning outcomes are not shown)

TABLE V. WEIGHTS OF CLUSTERS

	Goal	Criteria	Learning outcomes
Goal	0	0	0
Criteria	1	0,5	0
Learning outcomes	0	0,5	1

TABLE VI. PRIORITIES OF LOS

	LO1	LO2	LO3	LO4	LO5	LO6
AHP	0,1474	0,1372	0,17837	0,13891	0,2498	0,14813
ANP	0,1700	0,1305	0,14999	0,10931	0,2812	0,1587

4. DISCUSSION AND FURTHER RESEARCH

We establish four criteria for LO evaluation, and their weights as a result of group decision-making are given in Table II. The highest importance is given to criterion C1 (the importance of the topic for the future profession), as the majority of curriculum designers would expect. Two criteria, C2 (required level of the LO based on Bloom's taxonomy) and C3 (contribution to the development of 21st-century generic skills), were almost equally awarded. Finally, the lowest weight is given to C4 (student workload needed to fulfill the LO), and maybe that comes as a surprise. One explanation is that the criterion is implicitly incorporated in the C2 or C3. This means that criteria are not independent of each other. Let us point out that the consistency ratio for group work is excellent (CR=0,0041), which means that we can rely on the first phase results.

During our case study group decision making, there were still requirements for clarification asked from the evaluators. Therefore, there is a space for further improvement of the set of criteria and their descriptions. One can also argue that these criteria are context-sensitive, and there is a further research proposal to use focus groups in a different context and try to derive LO evaluation criteria.

Let us now discuss the second phase of decision making. In a hierarchical model result (Table III), the highest importance is given to LO5 (Effectively work in a team on problem posing and solving real problems related to graph theory and discrete mathematics), which is indeed the most complex learning outcome because it encompasses theory and practice. The second-highest score goes to LO3 (Apply theory and algorithms based on number theory on problems from cryptography) due to similar reasoning. More standard intended LOs are given a lower importance, and all weights are close to each other. Consistency ratios in all pairwise comparisons tables were under 0.1, as required.

The decision-making problem's network model contains the atypical existence of connections between the alternatives, i.e., learning outcomes. The final results of the ANP are similar but not the same as those obtained by the AHP. LO5, which has the highest rank in the AHP, scored even higher in the network model. However, second place is given to LO1 (Identify structures and types of proofs in mathematics), which is usually difficult for students, and it is the basis to really understand algorithms and not just memorize them. Again, LOs that have lover levels on the Bloom taxonomy are awarded lower.

The implementation of the ANP method requires much time. Also, some steps of the method are confusing and not understandable to many users [12]. There are some other characteristics of the method that contribute to its misunderstanding. These characteristics motivated the creation of a SNAP method that combines ANP with social network analysis (SNA) [13]. SNAP can be observed as a new variant of DEMATEL-ANP approaches [14]. In ANP, a high number of pairwise comparisons needs to be implemented to obtain final priorities. More precisely, in the ANP application in this paper, 119 pairwise comparisons in total should be made. The number of inputs that are needed for implementing SNAP is lower. In the presented case, it is 65. In ANP, users face misunderstandings of similar pairwise comparisons. E.g., comparing clusters Alternatives and Criteria with respect to Criteria, and then again comparing the same two clusters with respect to Alternatives. In the SNAP, we do not have to implement comparisons that are problematic in the ANP in terms of understanding specific pairwise comparisons. In ANP, the influence of the goal node on the priorities is lost. If we change the values in the first column, nothing will change in total priorities. SNAP combines strengths of elements with priorities of elements respecting the intensity of affecting. The stochasticity of the supermatrix in the ANP might also be a problem. The demand in the ANP is that the weighted supermatrix sum of all columns equals 1. This request relativizes the problem. For example, in our example criteria, C2 and C3 can have equal, but a high influence on the C1 – their priorities will be 0.5 and 0.5. If both can have equal but weak influence on the C1 – then also, the priorities will be 0.5 and 0.5. SNAP does not require a stochastic matrix of the problem: sums of columns do not have to be 1. Therefore, we recommend SNAP use in future research.

IV. PRACTICAL IMPLICATIONS ON ASSESSMENT

Once weights of learning outcomes are obtained, we can use constructive alignment to distribute weights throughout chosen assessment methods and particular tasks. Table VII. shows an example of how we do it on the DMGT course based on the AHP results.

The weights of six LOs range from 14% to 25% contribution to the total grade. We use three assessment methods: two written tests, ten quizzes, and problem-posing/problem-solving teamwork. Weights of LOs are distributed among assessment tasks. Each written test covers 30% of the total grade as well as problem-solving teamwork. Quizzes, whose purpose is primarily formative assessment, have a total of 10% contribution to the final grade. Further analysis has to be done to ponder assessment tasks and exercises according to the distribution of weights given in Table VII.

TABLE VII. DISTRIBUTION OF WEIGHTS THROUGHOUT CHOSEN ASSESSMENT METHODS

DMGT		**Assessment methods**		
Learning outcomes	Weight of LO	Written tests	Quizzes	Problem-posing and problem-solving
Define and classify binary relations on sets, knowing their properties and characteristic examples	14	12	2	
Define and connect fundamental notions and problems in the scope of graph theory	14	11	2	1
Effectively work in a team on problem posing and solving the real problem related to graph theory and discrete mathematics	25			25
Identify structure and type of proofs in mathematics	14	11	3	

Apply theorems and algorithms from graph theory to standard exercises from graph theory	15	13	2	
Apply theory and algorithms based on number theory to problems from cryptography	18	13	1	4
Weight	100	60	10	20

V. CONCLUSION

Engineering and technology management is a fast-growing field and supplying skilled professionals is essential. Therefore, universities should put extra effort into a curriculum design that includes the validity and reliability of assessment of the intended learning outcomes.

The paper presents a problem of the validity of assessment on a course level as an interesting problem from the pedagogical point of view and decision-making point of view. Ensuring the validity of the assessment is a necessary condition for acceptance of the assessment. To ensure validity, it is necessary to clearly align a course learning outcome with assessment methods and relate assessment tasks points to the relative importance of a learning outcome. Therefore, we establish a method for determining the relative weights of learning outcomes. The first phase in that process is finding criteria for the evaluation of learning outcomes. Four criteria (Importance of the topic or context for the future profession; Required level of the LO based on chosen taxonomy; Contribution to the development of the 21st-century generic skills and Student workload needed to fulfill the LOs) for learning outcomes evaluation were identified by a focus group. Then we use the AHP and the ANP approach to find weights of criteria and consequently learning outcomes. The case study of the Discrete Mathematics with Graph Theory course is used to illustrate the method and practical implications of research on the creation of a valid course assessment plan. One direction for future research might be a check on evaluation criteria in a new context.

Both hierarchy and network models are designed through several focus groups. Also, in giving judgments for determining criteria weights and learning outcomes priorities, group decision making was applied.

The problem is interesting from the decision-making point of view because we consider prioritization (not selection), and there are relations between the alternatives, i.e., learning outcomes are not independent of each other. This means that network models like SNAP can be used to upgrade the results.

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