Assessment of the Academic Load in a Curriculum Through an Optimization Model: Case Study of a Master Program

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Keywords: Optimization Model, Academic Load, Linear Programming, Curriculum, Mathematical Modeling.

Abstract: The evaluation of academic load is necessary and constitutes a fundamental process in the design and redesign of programs. This is because an excessive academic load can have academic consequences such as lag, as well as effects on mental health, including depression, anxiety, burnout, self-esteem problems, among others. Academic load is a complex and dynamic topic, resulting in the absence of a single approach to its study and measurement. In this sense, this work proposes a mathematical model of linear programming. The case study evaluated in Magister, a Chilean university. The results reveal an even distribution of academic load between semesters and courses within the program. As the semesters progress, the academic load tends to increase gradually. Integrated courses, such as Course 10 and Course 11, have higher loads compared to others. In the third semester there is variability in the academic load, with one course concentrating most of the study hours. In total, 294 hours of study are required to complete the program. A comprehensive review of academic load distribution is recommended to ensure an equitable and manageable educational experience for students.

1 INTRODUCTION

The academic load of a curriculum is a critical issue for educational institutions because it is necessary to guarantee the competences and skills established in an outcome profile (undergraduate or graduate profile). Therefore, the curriculum seeks to achieve the outcome profile through the definition of course contents and training periods. In this topic, the academic load of a course represents the total time that an average student must spend attending classes and studying independently (i.e., making lectures, projects, self-study, trainee, etc.) for obtaining the learning outcomes (Ünal and Uysal, 2014). For this reason, designing a curriculum involves several complexities, such as the challenge of ensuring accessibility and effectiveness of learning for all students, considering their diversity in terms of abilities, prior knowledge, learning styles, and special needs (Dantas & Cunha, 2020; Woodcock et al., 2022); the inclusion of excessive contents, generating curricular overload (Chen et al., 2023); the necessity of periodic curriculum reviews and updates for ensuring its relevance and effectiveness (Chen et al., 2023).

Regarding the academic load, optimization models have been proposed in the literature for establishing it. According to Lambert et al. (2006), one of the first models that dealt with this topic was the balanced academic curriculum problem (BACP) introduced by Castro and Manzano, (2001). The proposed model was an integer linear programming model, which sought to design a balanced academic curriculum by assigning courses to periods, guaranteeing a similar academic load in each period. The model was executed using synthetic instances, concluding that it could solve medium size problems. A few years later, Hnich et al., (2004) presented a hybrid modelling approach that combines a mixed integer linear programming model with a data-driven model. Additionally, the authors used machine learning techniques in order to forecast the course

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Gaete, M. and González-Araya, M.
Assessment of the Academic Load in a Curriculum Through an Optimization Model: Case Study of a Master Program.
DOI: 10.5220/0012365400003639

In *Proceedings of the 13th International Conference on Operations Research and Enterprise Systems (ICORES 2024)*, pages 269-276
ISBN: 978-989-758-681-1; ISSN: 2184-4372

demand. These authors also applied their approach to synthetic instances. They concluded that the hybrid model could increase the complexity of the problem. However, they did not mention conclusions about improvements in the academic load related to their approach. Based on the model presented by Castro and Manzano (2001), Lambert et al. (2006) developed a method for solving it, which combines two solution techniques: genetic algorithms (Holland, 1992) and constraint propagation (Jaffart et al., 1987). Genetic algorithms are used to generate solutions for the model of Castro and Manzano (2001), and to explore the solution space, while constraint propagation method is applied to improve the solutions, and to ensure the feasibility of the solutions. In 2012, Chiarandini et al. (2012) presented a generalized version of the balanced academic curriculum problem (BACP) proposed by Castro and Manzano, (2001) The new version of the model considers different curricula and professors' preferences and was solved by using a local search metaheuristic (Hoos, 2004). In this study, the authors used a real case study, corresponding to the curricula of an engineering school of Italy. The new model aimed to balance the academic curricula of all the engineering careers of the school simultaneously. Therefore, some limitations of the model discussed by the authors were: i) a course established in the curriculum for different engineering careers, one was scheduled for each career instead of defining only one for all careers; ii) the model did not balance the academic load of professors; iii) the increase in the number of elective courses made the model more complex; iv) engineering students could have some terms without courses because the model does not force that a course be carried out every term. Later, Ünal and Uysal (2014) presented a bi-objective mixed integer linear programming model, which was called relevant course balancing problem (RBCB). This model also seeks to balance a curriculum but considers two objective functions. One objective function minimizes the distance (relevant score) of relevant courses among periods, prioritizing scheduling these courses in a same period (zero distance). The other objective function minimizes the bias of the academic load per term. In this study, the authors used a real case study, corresponding to the curriculum of an undergraduate career from the industrial engineering department of Fatih University in Turkey. The proposed model enables consolidating loads of students per semester, meeting the prerequisite conditions. Furthermore, the authors compared their model with the BACP, where the RBCB generated better course timetabling solutions than the BACP. About this comparison, they concluded that the BACP can be solved faster than the RBCB. Nevertheless, the RBCB obtained optimal solutions in about 3–15 minutes, which is a reasonable time. It is important to highlight that none of the studies presented in the literature took into account the specific knowledges that need to be incorporated in each course, which are directly related to the academic load of a curriculum.

Regarding the taxonomy for classifying knowledges, the current literature has dealt with this issue as a peripheral topic (Tuma & Nassar, 2021). In education, the taxonomy is relevant because it classifies educational objectives into various cognitive levels, from the simplest to the most complex. The most known taxonomy is the Bloom's Taxonomy, proposed by Benjamin Bloom in 1956 (Choi-Koh, 2003), and it has had a significant impact on education by offering a well-organized framework for both curriculum design and the evaluation of learning (Tuma & Nassar, 2021). Moreover, this classification defines six levels of cognitive complexity, which are: remembering (remember facts and concepts); understanding (understand and explain the meaning of the information); applying (apply knowledge in new or specific situations); analyzing (divide the information into parts and understand their relationships); evaluating (judging the validity of information, arguments or methods); and creating (combining elements to form a new whole or create something new).

In the current study, a methodology that includes the development of a linear programming model for designing a curriculum is proposed. In this way, the developed model seeks to allocate knowledges to courses, where the courses have been pre-defined for each term. The objective of this allocation is to guarantee the achievement of competences and skills outlined in the graduate profile.

This article is structured as follows. Section 2 describes the proposed methodology to estimate the academic load. Section 3 presents a real case study, belonging to a Chilean university. Finally, the main conclusions are presented in Section 4.

2 METODOLOGY

The proposed methodology of this study has three key stages, which are described as follows.

- **Step 1. Rating Knowledges by an Expert Team.** In this step, the knowledges need to be rated for incorporating them as input parameters of the proposed linear programming model. Therefore, a multidisciplinary expert team is required to rate them. The rating process can be carried out by using the "developing a curriculum methodology."

- **Step 2. Execution of the Optimization Model for Estimating the Academic Load.** In this step, the proposed mathematical programming model is executed by using the parameters determined in the previous step. The model allows allocating the minimum number of knowledges to the courses, maintaining the defined academic load of each course, that is, the established academic credits of each course. Thus, excessive, or low academic load per term is avoided.
- **Step 3. Comparison of Results with the Current Curriculum**. The purpose of this comparison is to evaluate the quality and consistency of the current curriculum, and to propose improvements.

2.1 Model Knowledge-Based Curriculum Balance (BKCP)

For contextualizing the terms used in the proposed mathematical model, a schematic representation of a curriculum is shown in Figure 1.

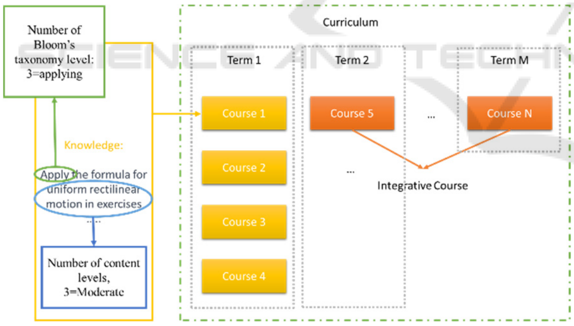

Figure 1: Schematic representation of a curriculum.

In Figure 1, the concepts as term, credit, content levels and Taxonomy Bloom's levels. A term consists in a group of courses dictated in the same period. Every course is associated with a specific set of knowledges. Furthermore, each knowledge is characterized by a action verb, quantified according to the Bloom's Taxonomy, that is, from 1 to 6. It is important to notice that every knowledge has a content, which is also assessed by experts regarding to its level of complexity, by using a scale from 1 to 6. On the other hand, in a curriculum, there are integrative courses designed to comprehensively address and evaluate the concepts' learning. These courses aim to foster the integration of knowledges and skills from diverse content areas.

Two examples regarding the different complexities of a content are described as follows. For example, a student could need more time to solve Quantum Physics exercises than Uniform Rectilinear Motion problems because the first content requires more knowledges. The similar situation can be observed in the taxonomic level. For example, memorizing axioms of probability requires less time than applying them. Finally, the academic period also influences the time required by a student for learning. For example, a first-year student may spend more time making a Python coding assignment than a senior student.

The proposed model seeks to assign knowledge assigned in each course and period of the program curriculum according to a Bloom j taxonomy level, at a content level of each knowledge. As mentioned previously, the objective of the proposed model is to allocate the minimal quantity of knowledges to courses, while guaranteeing the academic load requirements. In this way, it allows distributing the academic load of a curriculum to comply with the knowledges declared at graduation profile.

The linear programming model developed in this study, called as knowledge-based curriculum balance (BKCP), which is applied in the Step 2, is detailed as follows.

Definition of Parameters:
I = Number of courses,
J = Number of Bloom's taxonomy levels, where 1 = remembering, 2= understanding, 3= applying, 4= analyzing, evaluating=5 and 6=creating,
M = Number of terms in the curriculum,
K = Number of content levels, where 1= Very Easy, 2=Easy, 3=Moderate, 4=Difficult, 5= Very Challenging and 6= Extremely Difficult,
A = Set of integrative courses,
B_i = Set of terms from which the course i is excluded, i=1,…I,
CA_i = Number of credits per course i, $i = 1, …, I$,
SC = Minimum number of knowledge elements required per credit in the curriculum,
p_1 = Percentage of slack accepted between the declared credits and the credits assigned according to the model,
$V_{j,k,m}$ = The number of hours required by the student to acquire knowledge based on course I, Bloom's taxonomy level j, content level k, and term m, $j = 1, …, J$, $k=1, …, K$ and $m=1, …, M$,
MD = The maximum number of knowledges of the same course and content within a specific term.

Definition of the Decision Variables:
$x_{i,j,k,m}$= number of knowledge elements in course i with a Bloom's taxonomy level j, at a content level k, in a term m, i=1, …, I, j = 1, …, J, k=1, …, K and m=1, …, M.

Mathematical Formulation:

$$\text{Minimize} \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j,m,k} \tag{1}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{j=1}^{J} V_{j,k,m}\, x_{i,j,m,k} \le p_1\, CA_i, \quad \forall\, i = 1, \dots, I \tag{2}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{j=1}^{J} V_{j,k,m}\, x_{i,j,m,k} \ge p_2\, CA_i, \quad \forall\, i = 1, \dots, I \tag{3}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{i=1}^{I} x_{i,j_1,m,k} - \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{i=1}^{I} x_{i,j_2,m,k} \le MD, \forall j_1, j_2 \tag{4}$$

$$\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j,m,k} = 0, \forall\, j = 1, \dots, J \tag{5}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{j=1}^{J} x_{i,j,m,k} \ge SC \times CA_i\,, \quad \forall\, i = 1, \dots I \tag{6}$$

$$\sum_{j=1}^{J-1} x_{i,j,m,k} - \sum_{j=1}^{J-1} x_{i,j+1,m,k} \le 0, \quad \forall\, i = 1, \dots I, m = 1, \dots M, k = 1, \dots K \tag{7}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K} x_{i,j,m,k} = 0\,, \forall\, i = 1, \dots I, m \,\epsilon\, B_i \tag{8}$$

$$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j,m,k_1} - \sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j,m,k_2} \ge 0, \forall\, k_1, k_2 = 1, \dots K \tag{9}$$

$$\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j,m,k} \ge 0, \quad \forall\, k = 1, \dots K, m = 1, \dots M \tag{10}$$

$$x_{i,j,m,k} \in \mathrm{Z}^{+}, \forall\, i, j, m, k. \tag{11}$$

The objective function seeks to minimize the number of knowledge elements in the study plan. Constraint (2) ensures that each course has at least p_1 percentage of the academic load defined in the program. Constraint (3) ensures that courses cannot have more than p_1 percentage of the academic load defined in the program. Constraint (4) ensures that the number of knowledge elements by taxonomy is similar at different levels. Constraint (5) ensures that the course has knowledge elements according to the level where the course is located. Constraint (6) ensures that each course has at least SC knowledge elements for each of the assigned credits. Constraint (7) ensures that courses in the first period cannot have more knowledge elements of the highest taxonomy level than the sum of the knowledge elements of lower levels. Constraint (8) ensures equitable content coverage, while Constraint (9) ensures that the content is distributed equally across all semesters of the program. Constraint (10) guarantees the inclusion of all the required contents in each term. Constraint (11) establishes the nature of the decision variables.

It is important to notice that in the BKCP model, the parameter V represents the number of hours required by a student to acquire knowledges and skills. This parameter considers the complexity of the contents, the taxonomic levels, and the current academic period (term).

3 CASE STUDY

Below are the results, evaluating a 4-semester study program at Magister a Chilean university. The program consists of 98 SCT credits and 12 courses (of which the 11th and 12th are integrative courses), and the parameters can be found in the annexes of this work.

Each course has a different number of credits, integrative courses have a greater academic load, as can be seen in Table 1. Regarding the number of knowledges, currently the program has 101 knowledge. By analyzing this knowledge by semester, we can see that the curriculum has a large amount of high-level knowledge according to Bloom's taxonomy, in the first semesters of the program. The courses with the highest number of credits are in turn those with the lowest number of knowledges, which shows an imbalance in the academic load.

Table 1: Number of knowledges per course of the study program.

Semester	Course	Credit	Bloom's Taxonomy						Total
			1	2	3	4	5	6	
1	1	5	4	5	2		1		**12**
	2	5			10				**10**
	3	5		2		1	2	2	**7**
	4	5					4	4	**8**
Total 1		20	4	7	12	1	7	6	**37**
2	5	5	1		6	2	1		**10**
	6	5				10			**10**
	7	5					3	3	**6**
	8	2				3			**3**
	9	5	1		1		1	3	**6**
Total 2		22	2	0	7	15	5	6	**35**
3	10	2					3	1	**4**
	11	26		1			8	9	**18**
Total 3		28	0	1	0	0	11	10	**22**
4	12	28					3	4	**7**
Total 4		28	0	0	0	0	3	4	**7**
Total		**98**	**6**	**8**	**19**	**16**	**26**	**26**	**101**

3.1 Model BKCP Results

The results reveal a substantial redistribution of knowledge, with a notable increase from 101 to 336 units of knowledge. This increase is primarily attributed to the higher levels of Bloom's taxonomy (levels 4, 5, and 6). In terms of knowledge allocation per course, those with 5 credits are associated with 15 units of knowledge distributed across various levels

Table 2: Model BKCP results.

Semester	Course	Bloom's Taxonomy						Total
		1	2	3	4	5	6	
1	1		3		3		9	15
	2			5	1	1	8	15
	3		3	1	2		9	15
	4		1		14			15
Total 1		0	7	6	20	1	26	60
2	5			5	7		3	15
	6		4			1	10	15
	7		1	1	12	1		15
	8			4		11		15
	9	1					5	6
Total 2		1	5	10	19	13	18	66
3	10		24			42	12	78
	11			2	4			6
Total 3		0	24	2	4	42	12	84
4	12	55	20	38	13			126
Total 4		55	20	38	13			126
Total		**56**	**56**	**56**	**56**	**56**	**56**	**336**

When considering the knowledge distribution in integrative courses, the model suggests an increase of over 70 units of knowledge. This substantial increase is due to the considerably higher load of these courses compared to other courses in the curriculum.

3.2 Comparison of Model Results with the Current Learning Path

The current program has only one-third of the knowledge items that the mathematical model identified as optimal. According to the comparison presented in Table 1, the existing pathway demonstrates a notably lower quantity of high-level cognitive knowledge. As a result, from a curricular perspective, questions may arise regarding students' achievement of the specified competency levels.

In analyzing the distribution of knowledge by Bloom's Taxonomy and content, we can appreciate that the results of the BKCP model diversify the distribution of the academic load. This translates to none of the 6 identified contents being at the highest level of Bloom's Taxonomy (Figure 2 and 3).

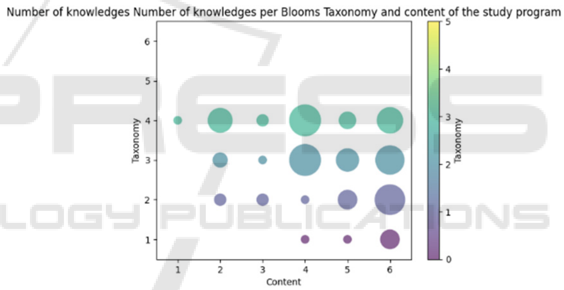

Figure 2: Number of knowledges Number of knowledges per Bloom's Taxonomy and content of the study program.

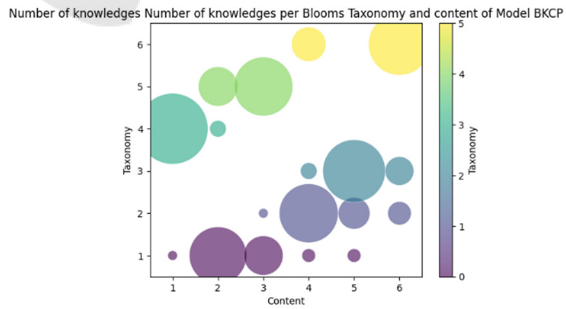

Figure 3: Number of knowledges Number of knowledges per Bloom's Taxonomy and content of Model BKCP.

Furthermore, a disparity in the quantity of knowledge among courses in the first and second semesters is noticeable, despite all these courses having the same number of credits.

On the other hand, when we analyze courses 10 and 11, which were defined as integrative knowledge courses, the number of knowledge items is low.

4 CONCLUSIONS

There is an unequal distribution of academic load across different semesters and courses. Notably, courses like Course 6 in the second semester and Course 10 in the third semester exhibit significantly higher loads compared to others.

Certain courses, such as Course 10 and 12, carry notably heavier academic burdens compared to their counterparts. This demands special attention to ensure students can effectively manage their load.

Across all semesters and courses, a total of 336 areas of knowledge is required, providing a comprehensive overview of the complete academic load within the program.

Concerning the distribution of academic load based on Bloom's taxonomy, it becomes evident that knowledge at the lower taxonomy levels is predominantly concentrated in the first two semesters, while higher-level knowledge in Bloom's taxonomy is predominantly concentrated in the later semesters.

For future research, it is advisable to consider the incorporation of additional variables into the model, including soliciting student feedback on their courses. In addition, the inclusion of prerequisites for each course would be considered, as has carried out in the study of Lambert et al., (2006).

ACKNOWLEDGEMENTS

MSc Myriam Gaete G. would like to thank CONICYT PFCHA/BECA DE DOCTORADO NACIONAL/2021 under Grant 21211324 for its financial support. Moreover, DSc Marcela González-Araya would like to thank FONDECYT Project 1191764 (Chile) for its financial support.

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APPENDIX A

Valuation of academic load by type of knowledge.

Bloom's Taxonomy	Content	Semester	Value
1	1	1	54,00
2	1	1	27,00
3	1	1	18,00
4	1	1	13,50
5	1	1	10,80
6	1	1	9,00
1	2	1	27,00
2	2	1	13,50
3	2	1	9,00
4	2	1	6,75
5	2	1	5,40
6	2	1	4,50
1	3	1	18,00
2	3	1	9,00
3	3	1	6,00
4	3	1	4,50
5	3	1	3,60
6	3	1	3,00
1	4	1	13,50
2	4	1	6,75
3	4	1	4,50
4	4	1	3,38
5	4	1	2,70
6	4	1	2,25
1	5	1	10,80
2	5	1	5,40
3	5	1	3,60
4	5	1	2,70
5	5	1	2,16
6	5	1	1,80
1	6	1	9,00
2	6	1	4,50
3	6	1	3,00
4	6	1	2,25
5	6	1	1,80
6	6	1	1,50
1	1	2	48,00
2	1	2	24,00
3	1	2	16,00
4	1	2	12,00
5	1	2	9,60
6	1	2	8,00
1	2	2	24,00
2	2	2	12,00
3	2	2	8,00
4	2	2	6,00
5	2	2	4,80
6	2	2	4,00
1	3	2	16,00
2	3	2	8,00
3	3	2	5,33
4	3	2	4,00
5	3	2	3,20
6	3	2	2,67
1	4	2	12,00
2	4	2	6,00

Bloom's Taxonomy	Content	Semester	Value
3	4	2	4,00
4	4	2	3,00
5	4	2	2,40
6	4	2	2,00
1	5	2	9,60
2	5	2	4,80
3	5	2	3,20
4	5	2	2,40
5	5	2	1,92
6	5	2	1,60
1	6	2	8,00
2	6	2	4,00
3	6	2	2,67
4	6	2	2,00
5	6	2	1,60
6	6	2	1,33
1	1	3	42,00
2	1	3	21,00
3	1	3	14,00
4	1	3	10,50
5	1	3	8,40
6	1	3	7,00
1	2	3	21,00
2	2	3	10,50
3	2	3	7,00
4	2	3	5,25
5	2	3	4,20
6	2	3	3,50
1	3	3	14,00
2	3	3	7,00
3	3	3	4,67
4	3	3	3,50
5	3	3	2,80
	3	3	2,33
1	4	3	10,50
2	4	3	5,25
3	4	3	3,50
4	4	3	2,63
5	4	3	2,10
6	4	3	1,75
1	5	3	8,40
2	5	3	4,20
3	5	3	2,80
4	5	3	2,10
5	5	3	1,68
6	5	3	1,40
1	6	3	7,00
2	6	3	3,50
3	6	3	2,33
4	6	3	1,75
5	6	3	1,40
6	6	3	1,17
1	1	4	36,00
2	1	4	18,00
3	1	4	12,00
4	1	4	9,00

Bloom's Taxonomy	**Content**	**Semester**	**Value**
5	1	4	7,20
6	1	4	6,00
1	2	4	18,00
2	2	4	9,00
3	2	4	6,00
4	2	4	4,50
5	2	4	3,60
6	2	4	3,00
1	3	4	12,00
2	3	4	6,00
3	3	4	4,00
4	3	4	3,00
5	3	4	2,40
6	3	4	2,00
1	4	4	9,00
2	4	4	4,50
3	4	4	3,00
4	4	4	2,25
5	4	4	1,80
6	4	4	1,50
1	5	4	7,20
2	5	4	3,60
3	5	4	2,40
4	5	4	1,80
5	5	4	1,44
6	5	4	1,20
1	6	4	6,00
2	6	4	3,00
3	6	4	2,00
4	6	4	1,50
5	6	4	1,20
6	6	4	1,00