

The most decisive study difficulties identified by a cluster analysis examining STEM higher education

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ABSTRACT

The main goal of the research is to create a value-added model for STEM higher education. In this research we approached dropout as a loss element with a special examination. The target was to identify the background factors proved to be the most decisive study difficulties that could be converted into the value-added model. Another important research objective was to examine the educational attitudes, similarities, and differences between institutional and higher education groups of freshstart and of real dropout. We identified cluster analysis as a well-suited method for answering research questions. By using the cluster analysis R Project Rankcluster, we have made homogeneous groups of study difficulties rankings visible, by treating responses to the further higher education plans as a second dimension. Two cluster analyses were carried out to distinguish institution and higher education loss. The findings of these analyses show that "interest in other training" increases the chances of staying in the higher education. Other decisive factors such as "critical subject(s)", "lecturer was not inspiring" proved to be also important. Due to the findings the most important background factors became identifiable, so we can move forward a leaner model to the essence of value added of STEM higher education.

Keywords: Freshstart; Dropout; Study difficulties; STEM higher education; Cluster analysis.

1. Opening thoughts

The main goal of the research is to create a possible value-added model of technical/STEM (Science, Technology, Engineering and Mathematics) higher education. I narrowed the focus of the research to the technical or STEM training field because, on the one hand, the responsibility and role of technical higher education is outstanding in terms of sustainable development. On the other hand, due to the turbulence of technological development, the danger of innovation/technological competition and education drifting away is most intense here. During the research several approaches (qualitative and quantitative) have been used to unveil the critical factors of the value-added of STEM higher education. Grabbing the philosophy of lean management², we consider dropout as a loss element of the value-added model, so by examining dropout we can approach the elements of VAM in an inverse way. This is a particularly important aspect regarding technical higher education, as the technical training field is a more vulnerable area than the non-technical one in terms of the proportion of student who have stopped their studies without a qualification (Harkányi, 2018). Furthermore, it can be said that technical/STEM higher education is particularly affected in terms of the high proportion of those who leave the training without a degree. The technical bachelor's degree is characterized by 40-44%, natural science and IT bachelor's degree fields with close to or more than 50% dropping out without a degree (Demcsákné, 2020). Szigeti et al. (2021) in their study Types and Characteristics

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²The Massachusetts Institute of Technology (MIT) officialized by its American researchers Lean Management is a value-added management and development approach that focuses on increasing the ratio of activities and resources that add value to customers and employees, while all resources and activities that do not produce value are considered unnecessary, and thus consider them losses and strive to minimize them with continuous self-reflection.

of Student Progression highlighted that the field of education has been shown to be the most important predictor of the higher education career path. Taken recent international publications into considerations I found some interesting articles with a focus on technical higher education (Mészáros, 2022). As the common feature of these studies - Routaharju (2022), Nematov (2022), Eshpulatovich (2022) - that technical higher education demands a common approach, Gallery (2021) suggests that a focus on the process of engineering identity formation could play a crucial role in the education of the next generation of engineers. Universities need to address a well-structured system of 'who, what and how to teach' aspects to train engineers appropriately for the labour market. Examining loss factor, we have looked for the reasons and characteristics of study difficulties along dimensions of student, lecturer, institution, and supporting networks by conducting a questionnaire-based study among students who have terminated/interrupted their student relationships. Our target to find answers to the question of whether patterns can be found concerning the cases of dropout students with which certain elements highlighted can be positioned in the value-added model. Another research goal is to refine and categorize dropout as a loss, and to detect the patterns that can be used to better understand the causes, factors, and value-added elements behind dropout. Approaching the analysis of the questionnaire findings we carried out contingency analyses, association-, and rank correlation studies to unveil the relationships of study difficulties. The cluster analysis presented in this article examines homogeneous groups detectable at the intersection of study background factors and dropout types has brought new light to the research. It is worth emphasizing that the research's basic goal is to create a value-added model; examining the background factors of dropout serves to support the main target.

2. Research purpose and questions

How to categorize dropout? From whose point of view does it manifest itself as a loss? This was one of the significant research questions related to the analysis of the questionnaire. It should be emphasized that in our interpretation, dropouts are represented by students who have left the started training without a degree. This makes the definition broader, including students who interrupted and then restarted a training in the same institution, and perhaps graduated later.

By our definition a dropout student's reason for the closure of the training is: exceeding the permissible number of unsuccessful remedial and repeating exams, failure to log in more than allowed; arrears of payment in training; disqualification by disciplinary decision; non-compliance with training obligations; own notification of interruption of training; application for transfer to another higher education institution; change of training within the institution.

Analysing the sample and the basic population, the phenomenon of freshstart (re-admission) has already emerged, i.e., that in many cases the resumption of studies follows the termination of the legal relationship (which, according to the answers, is in many cases followed by a successful graduation sooner or later). That is why we use the term termination/interruption of legal relationship. In this study, for a deeper examination of dropout, we sought to answer the question of what patterns can be found in the studied sample between study difficulties and the situation of further education. By transforming the situation of further education into a binary code, it became possible to distinguish between a group that stays in or leaves an institution (institutional loss) and a group that stays in or leaves higher education (social loss).

The research question concerned whether: 1) what homogeneous groups can be identified at the intersection of study difficulties and the situation of further education? 2) the study of these homogeneous groups reveals patterns for the value-added model.

The basic aim is to examine also from this perspective that which study difficulties prove to be the most decisive background factors transferable to the value-added model. Another important goal is to examine the academic attitudes of the remaining and leaving groups of institutions and higher education, the similarities and differences between them, and to form a picture of their study difficulties from this point of view as well.

3. The questionnaire and sample

The causes of study difficulties were conceptualized and operationalized along four dimensions - student, lecturer, institution, support networks (Babbie, 2001). The research is highly focused on aspects that are easy to evaluate and define while maintaining the main dimensions of the model. Consequently, certainly important personal variables of student success (e.g., cultural capital, personal competencies and motivations, sociological status characteristics) or, for example, institutional culture factors are not included in our model. To remedy this, we placed possibilities for free text supplement on several questions with the indication "other". Analyzing free worded answers helped to extend beyond the general framework of our model, refining and enriching it (Mészáros, 2021a). To eliminate the middle scale value a four-element ("fully", "decisive", "uncharacteristic", "not at all") Likert scale was used. By treating the further education situation in the institutional and higher education dimensions as already described, we have made it binary according to the stay or leave situation.

Two designated STEM institutions produced an evaluable sample (n=863), of which the sample of the present sub-research is 691 and 625, respectively, in terms of relevant questions (this is how many answers we received for the first and second questions that are now relevant). The questionnaire was sent out and could be filled out via the central study system ensuring complete anonymity to students who terminated their student status upon their own request or because of other circumstances. Selecting a 5-year time horizon, the questionnaire was sent to the students from STEMscience, Technology, Engineering and Mathematics courses affected from January 1st 2015 to the first semester of 2020. When the number of respondents did not change noticeably, we closed the questionnaires in July and November 2020.

Compering the basic population and our sample, some important findings could be highlighted:

- the sample is not representative;
- changes in internal proportions can also be caused by time departure from the event, changes in aspects (institution versus student), and anonymity;
- in both the sample and the core population, a significant proportion is represented by self-reported interrupters (in these cases we only know that termination was initiated by the student), which is thus a category worthy of increased attention;
- in the sample, the proportion of dropouts indicating the reason for non-fulfillment of obligations decreases, but at the same time the phenomenon of re-admission (change of training within the institution) appears strongly, offering (almost as if changing places) an additional deep drilling point (Since one of the main motifs of the questionnaire focuses on the background factors of possible study difficulties, this discrepancy does not cause any particular headaches, but at the same time draws attention to the phenomenon of re-admission, which is a kind of focus of this partial research.);
- the fact that both samples have a higher proportion of students citing academic failure (more exam repetitions than allowed), the frustration that may come with this should be addressed during evaluating the results. Based on this, it is possible that the emotional background factors of study failure are overrepresented, which, however, can be handled well in terms of the value-added model being researched.

Summarizing, the pattern is a manageable mapping of the core population, but a multifaceted approach and careful conclusions of analytical aspects to be followed.

4. Research history

With the questionnaire study among the students who have dropped out from STEM courses we asked the target group about the personal and official reasons for their termination of their legal relationship, the number of semesters spent in the institution in connection with the relevant training, the background factors of their possible academic difficulties, their further education situation, the housing during the training and some characteristics describing the training concerned. In the first phase of the analysis of questionnaires, association and contingent studies and rank correlation analyses were typically performed (Babbie, 2001) (Molnár, 2007).

Based on these, the most significant study difficulties were identified, and the association relationship revealed showed that there is a significantly verifiable correlation/co-movement in certain background factors of study difficulties (Mészáros, 2021b). For both institutions, the framework of the relationship map was represented by the same background factors of study difficulties: "learning methods" (student dimension), "one or more critical subjects" (institutional dimension), and "consistency of assessing and requirements" concerning the teacher dimension, "system of assessing", "instructor not inspiring", "quantity/quality of supporting curriculum". At both universities, the educational dimension proved to be the focus.

4.1. Research method

To answer current research questions - (1) What homogeneous groups can be identified at the intersection of study difficulties and the situation of further education? (2) What patterns can be revealed by the analysis of these homogeneous groups for the value-added model? – we have identified cluster analysis forming homogeneous groups as a well-suited method. In relation to the research questions examined presently, the questionnaire uses ordinal (study difficulties) and nominal (further education) measurement scales, and we need to examine two dimensions (study difficulties and further education situation) at the same time. The question examining academic difficulties asks the respondent to rank 17 variables, i.e. to judge how decisive each variable was in his or her academic study difficulties. Thus, one by one, respondents ranked the variables that caused their academic difficulties on a scale of four. These rankings were transformed using a rank function by ranking the 17 variables relative to each other for each respondent. With this, we created the conditions for a rank cluster analysis, with which we were able to form homogeneous groups based on the order of preference (relative ranking of the factors of study difficulties in a 17-vectored field). The two institutional samples were treated as one.

Considering the identified specifications, to investigate attitude ranking we used a method called R Project Rankcluster (Jacques, Grimonprez & Biernacki, 2020), which uses a model-based clustering algorithm to analyze the data. This algorithm represents an extension of the ISR (Insertion Sorting Rank) model to the ranked data (Biernacki & Jacques, 2013). The algorithm modeling by pairwise comparison is well suited for the study of multidimensional cases, so we identified it as an excellent cluster analysis procedure for our research. The procedure is non-hierarchical clustering: individual respondents may have given significantly different answers from the established groups, yet the groups characterize the majority of respondents well. The ISR algorithm is highly recommended for "human ranking" modeling (Biernacki & Jacques, 2013, 2). In our case, the complexity of the model is special, since there are 17 variables in the first dimension and 2 in the second, which is far from typical in the literature read so far by us (they work with 4-5 variables).

The questionnaire addresses 17 study difficulty background factors on a four-grade Likert scale, and the further education situation also has four attributes. As already mentioned, the background factors were transformed using a rank function by ranking the 17 variables relative to each other for each respondent, with the most important factor in 1st place. With the cluster analysis, homogeneous groups of rankings of study difficulties were visualized, treating the responses to the further learning situation as a second dimension. Based on the rankings of study difficulty variables and the categories of further education, the cluster analysis was carried out along two dimensions: dimension_1: background factors of study difficulties, dimension_2: loss.

Following the interpretation of the loss dimension, two cluster analyses were defined:

- 1) Institutional loss approach: dropout from the point of view of the institution as a second dimension. In this case, whoever leaves the institution is considered a loss (dummy_0= I start my studies again - stays; dummy_1= I continue in another institution, abroad, I will not continue - institutional loss).
- 2) Social loss approach: dropout from the point of view of higher education and society as a second dimension. Here I interpreted as a loss only the answer "I will not continue my studies", otherwise dummy_0= stay in higher education (re-admission, go to another domestic or foreign institution); dummy_1=loss of higher education (I will not continue my studies)

The results should be interpreted as the digits indicated next to each study difficulty indicate the order of ranking of response options in the given cluster. The subject of the study is to highlight the significant similarities and

differences of study difficulties among cluster groups and to find connection to the institutional and social loss dimension.

Based on the analysis of homogeneous groups formed in terms of institutional and social loss, the most decisive background factors were established as follows, based on the sub-studies of institutional and social cluster analysis with and without missing data.

1. As a first step, we looked at whether the given study factor was in the top six in at least one of the homogeneous groups that were formed. These factors are marked as important (red), they should be not omitted in further examination.
2. As a second step, factors that were in the top three places for homogeneous groups of the complete sample were also identified as important factors, even if they do not occur in the top six places for the subgroups.
3. Based on these, it becomes visible which factors are important (red) and can be set aside (green) in institutional and social cluster analysis.

We carried out two studies, one with the missing data and another without the missing data. Since the study without the missing data is free from certain biases, I gave these results a greater role in drawing the final conclusions.

4.2. Results of institutional cluster analysis

In the cluster analysis of institutional loss, the formation of four homogeneous groups for the study with missing data and two groups for the analysis without the missing data proved to be statistically significant.

Table 1. Institutional cluster analysis

Name of the cluster analysis	Institutional analysis		with missing data				without missing data			
			IVcl	IV_c11	IV_c12	IV_c13	IV_c14	lcl1	lcl1	lcl2
Proportion			0,1112	0,1854	0,1425	0,5608	complete	0,3928	0,6072	
Strenght of the group/Ratio of entropy ³ =0,4			22%	39%	27%	48%		51%	63%	
Clusters		IVcl	IV_c11	IV_c12	IV_c13	IV_c14	lcl1	lcl1	lcl2	
Study difficulties, dimension_1	1	scheduling	8	9	4	8	8	1	9	12
	2	learning methods	6	3	8	11	16	17	13	2
	3	learning difficulties (I don't understand)	1	1	9	16	6	8	14	3
	4	interest in other training	12	13	3	7	13	11	1	9
	5	unclear requirements	7	15	7	10	7	7	16	14
	6	assessment are not harmonized with requirements	3	5	14	9	3	6	8	11
	7	critical subject(s)	5	4	1	3	1	4	2	1
	8	assessment system	14	8	16	1	15	9	15	5
	9	professional competence of the lecturer(s)	16	16	15	5	10	16	5	6
	10	the lecturer was not inspiring	4	12	10	2	5	3	17	15
	11	the lecturer did not follow my progress	17	2	12	4	9	12	4	7
	12	supporting curriculum	15	14	2	14	2	2	6	10
	13	learning auxiliaries	10	11	17	12	14	5	7	13
	14	modern ICT	9	10	13	15	11	13	3	8
	15	access to student services	11	7	11	6	12	15	10	16
	16	I felt alone with my problem(s)	2	6	5	13	4	14	11	4
	17	other	13	17	6	17	17	10	12	17
Loss, dimension_2	Institutional loss	0	0	0	0	1	0	1	0	

Source: own edit

In terms of ratios, it is interesting that in both sub-studies there is a cluster with decisive weight (IV_c14, lcl2). It can be also concluded that a group of dropout can be identified in both sub-tests (IV_c14, lcl1). If we look at the proportion of students who closely belong to these groups (calculated as the ratio of the number of group members with less than or equal entropy³ values of 0.4 to the total number of group members), it is high for both groups (48% and 51%, respectively). That is, for these groups, the results are expected to reliably reflect the study difficulty ranking of those leaving the institution.

³An indicator indicating the strength of belonging to a group, the smaller the value, the closer the bond (authors' note).

In the sub-study which included missing data the cluster of those leaving the institution (IV_cl4) identified in the first three places the difficulties caused by the *critical subject(s)*, *the qualitative or quantitative inadequacy of the supporting curriculum*, and *the inconsequence between assessment and requirements*, i.e. factors typically belong to institutional and teaching/educational competence. Add to these factors students relevant *feel alone with their problem(s)*, *have difficulties due to the lecturer's motivating power*, and *have learning difficulties*. Therefore, difficulties from the student, lecturer, institutional and network side concerned. For the sake of easier identification, this cluster has been named after its main characteristics as *"got stucked alone, dissatisfied with the quality of the institution and educator"*. They represent a real loss for the institution. If we look at the cluster of dropouts from the institution in the study without missing data (Icl1), we get different results in many respects. In the top three places, *interest in other fields of training*, *difficulties caused by critical subject(s)* and *lack of modern info communications tools* were identified. The additional variables are the *instructor did not follow my progress*, *he was not professionally properly prepared*, and *the shortcomings of the supporting curriculum*. There is a significant difference between the two sub-studies, only the critical subjects and supporting curriculum factors are the same (I have to emphasize that both groups are dissatisfied with the lecturer/education pointing from different point of view). I named the dropout group resulting from the sub-study without missing data as the cluster *"interest in other training fields, got stucked, dissatisfied with the quality of the institution and educator"*. No student and network difficulty dimensions are displayed here. As a result of the comparative analyses within and between the clusters, based on the sub-examination of the institutional cluster analysis with the missing data, the three clusters remaining in the institution were given the following names (Mészáros-Takács,2022): 1) "alone with learning and integration difficulties", 2) "got stucked and insecure alone", 3) "dissatisfaction with education, educators, institution critics".

If we examine the institutional sub-study without missing data, a strong homogeneous group represents students who interrupt their studies but are unlikely to leave their institution. In the top three are the difficulties of *the critical subject(s)*, *the learning methods and difficulties of the student*. This is followed by *feeling alone with my problem*, *assessment system and dissatisfaction with the professional competence of the teacher*. This group seems to combine the main characteristics of the three homogeneous groups with missing data, simultaneously encompassing students with learning, educational, institutional problems, who probably chose to freshstart.

4.3. Results of social cluster analysis

In the case of social analysis we also distinguish between sub-examination with missing and without missing data. In both sub-studies, three homogeneous grouped model was found to be statistically significant. Figures of Table 2 show that the cluster of TV_cl2 in sub-study with missing data shows a fairly small proportion and poor group cohesion. In sub-study without missing data, it should also be noted that one dominant group was formed (Tcl3), the other two are very faint in proportion and weak at group cohesion as well. These findings are essential to consider evaluating the results.

Table 2. Social cluster analysis

Name of the cluster analysis	Social analysis	with missing data				without missing data			
		Proportion	0,5759 40%	0,0695 15%	0,3546 58%	complete	0,0403 38%	0,0203 18%	0,9392 71%
Strength of the group	Ratio of entropy = 0,4	Tvd	TV_cl1	TV_cl2	TV_cl3	Tcl	Tcl1	Tcl2	Tcl3
Study difficulties, dimension_1	1 scheduling	12	12	3	8	1	6	1	9
	2 learning methods	4	6	15	14	12	10	15	14
	3 learning difficulties (I don't understand)	13	9	4	12	7	7	17	8
	4 interest in other training	1	2	1	9	3	16	7	4
	5 unclear requirements	16	7	11	7	15	15	16	11
	6 assessment are not harmonized with requirements	14	14	9	4	11	12	6	2
	7 critical subject(s)	2	3	13	1	4	2	14	5
	8 assessment system	5	1	10	2	5	3	2	12
	9 professional competence of the lecturer(s)	10	8	2	6	10	8	10	16
	10 the lecturer was not inspiring	8	13	16	5	8	1	4	7
	11 the lecturer did not follow my progress	9	11	6	13	9	5	13	15
	12 supporting curriculum	11	4	5	3	13	4	12	1
	13 learning auxiliaries	15	16	7	16	14	14	8	3
	14 modern ICT	7	5	14	10	16	9	11	10
	15 access to student services	6	15	17	15	6	13	9	13
	16 I felt alone with my problem(s)	3	10	8	11	2	11	3	6
	17 other	17	17	12	17	17	17	5	17
Loss, dimension_2	Social loss	0	0	0	1	0	0	0	0

Source: own edit

Remarkable is that there is no group representing social loss, i.e. dropouts from higher education, in the study without missing data. In the analysis with missing data the proportion and group strength of the leaving group is "acceptable".

In sub-study with missing data those leaving higher education, i.e. the cluster of social loss (TV_cl3), *the critical subject(s), assessment system, the lack of a supporting curriculum* lead the ranking, followed by a negative experience for almost factors of educational systems and teachers. They are best suited for the adjective "disillusioned, got stucked". The other two homogeneous groups remaining in higher education have the following main characteristics:

- "dissatisfied with the quality of the institution and education, interest in other training fields" (TV_cl1)
- "interest in other training fields" (TV_cl2)

In the first homogeneous group (TV_cl1), *the system of assessment, interest in other fields of training and the factors of the critical subject(s)* are the most decisive, followed by the supporting curriculum, the lack of modern info communications, and student learning methods. Based on these, the cluster was named "dissatisfied with the quality of the institution and education, interest in other trainings".

If we look at cluster 2 (TV_cl2) of the sub-study with missing data it is striking that *interest in other fields of training* tops the list, followed by *professional competence of the instructor, and student's learning difficulties*. In addition, the *lack of a supporting curriculum and teacher support* appears. According to the list, the most important thing is that they are interested in a different field of training, that is why they received the name "interest in other trainings".

The homogeneous groups formed during the sub-study without missing data were named as follows based on their characteristics:

- "lack of support" (Tcl1)
- "dissatisfied with organization, lecturer, alone" (Tcl2)
- "dissatisfied with the support of the education system, interest in other trainings" (Tcl3)

The similarities between the "lack of support" (Tcl1) group and the "dissatisfied with the organization, lecturer, alone" (Tcl2) groups are that both groups identified factors with the student scheduling, assessment system and "the lecturer were not inspiring". However, the "lack of support" group also prioritized the *critical subject(s), "lecturer did not follow my progress" and put the lack of supporting curriculum in a prioritized position*. In the cluster "dissatisfied with organization, lecturer, alone", the background factors are *disharmony in assessment-requirements, "I felt alone with the problem" and "other*.

The preferred background factors of the *most prominent homogeneous group of sub-study without missing data*(Tcl3) in order of priority are: *supporting curriculum, inconsistency of assessment-requirements, learning auxiliaries, interest in other field of training, critical subject(s), feeling alone with the problem*. There is a sense of dissatisfaction with the education system and isolation. That is why they received the name "*dissatisfied with the support of the education system, interest in other trainings*".

5. Summary and outlook

Using cluster analysis, homogeneous groups were identified at the intersection of study difficulties and the situation of further education. Distinguishing between institutional and higher education losses, two cluster analyses were carried out with and without missing data.

As a result of comparative analyses without missing data two clusters of institutional analysis were named as follows: (1) "*interest in other fields, got stucked, dissatisfied with the quality of lecturers and institution*" – *dropout cluster*; "*struggling with learning, lecturers, educational system, alone*" - *freshstart cluster*.

In the same way, three clusters of social cluster analysis were distinguished: 1) "*lack of support*"; 2) "*alone and dissatisfied with the educational system and lecturer*"; 3) "*dissatisfied with the support of educational system, interested in other fields*".

The rows in Table 3 highlighted in blue show the background factors that were top ranked in both analyses. Background factors written in red are important factors, and in green the ones were not important one of the analyses. The rows highlighted in gray indicate factors that might be omitted based on the results of the cluster analysis.

Table 3. Results of institutional and social cluster analysis

Institutional analysis	Social analysis
scheduling	scheduling
learning methods	learning methods
learning difficulties (I don't understand)	learning difficulties (I don't understand)
interest in other training	interest in other training
unclear requirements	unclear requirements
assessment are not harmonized with requirements	assessment are not harmonized with requirements
critical subject(s)	critical subject(s)
assessment system	assessment system
professional competence of the lecturer(s)	professional competence of the lecturer(s)
the lecturer was not inspiring	the lecturer was not inspiring
the lecturer did not follow my progress	the lecturer did not follow my progress
supporting curriculum	supporting curriculum
learning auxiliaries	learning auxiliaries
modern ICT	modern ICT
access to student services	access to student services
I felt alone with my problem(s)	I felt alone with my problem(s)
other	other

Source: own edit

There are fewer of the latter, which include only “access to student services” and “unclear requirements”. Also, based on subjective judgement, I add the “other” factor, even though it appeared as the 5th most important factor in one of the groups of social inquiry. I use a different method of research to examine the other factor, so I did not engage this factor at this point of study.

Worth emphasizing that each dimension examined are proved to be top ranked with some factors in both analyses, such as student scheduling, interest in other trainings, critical subjects, lecturer was not inspiring or did not follow student’s progress, supporting curriculum and feeling alone with the problem(s). Therefore dilemmas of what, who and how to teach are still in the focus based on our sample.

Due to the factors have been analyzed so far, it seems that interest in other training is a key factor in terms of institutional dropout. A further field to be explored calls for the determinants of social loss⁴.

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⁴Here we could not identify a loss group for the test without missing data.

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