Assessing the Propensity for Interdisciplinary Development of the Doctoral Scientific Fields in the Academic Research Case Study: The Bucharest Academy of Economic Studies

C. Lincaru, V. Ciuca, L. Mladen, and D. Atanasiu

***Abstract*—** In this paper we intend to evaluate the probability of development of interdisciplinary field of science as a result of finalized doctoral thesis. We assume that every finalized doctorate thesis can be described by a vector with three dimensions. First dimension is given by the position in the doctoral scientific field taxonomy (at national level), the second is set by the position in the advanced high education program taxonomy (ISCED 6-7) and the third dimension reflects the place occupied in an international scientific taxonomy. The relative positioning to the frontier of the new in the taxonomy's coordinates offer the opportunity to evaluate the distributions of the probability density for chosen dimensions by application of the Generalized EM and k-Means Cluster Analysis.

***Keywords*—** academic research, doctoral process, interdisciplinary field, interdisciplinary research

I. Introduction

SCIENTIFIC literature revealed that interdisciplinary research has won a greater significance over the last years. Professional attention to interdisciplinary research emerged in the 1970s and flourished into the 1980s, then paled. Now, it appears to be on an ascending trend again. J.T. Klein [1] attests that "the roots of the concepts lie in a number of ideas that resonate through modern discourse - the ideas of a unified science, general knowledge, synthesis and the integration of knowledge". She noted that there are many interdisciplinary varieties among which we can find "interdisciplinary field of study". Chubin et al [2] argue that interdisciplinary research should not be conceptualized with "discipline" as the basic "indivisible" unit. Darden and Maull [3] suggest that a definition of interdisciplinary research should not refer to disciplines, but to research fields.

We have started from the idea that "an *interdisciplinary field* is a field of study that crosses traditional boundaries between academic disciplines or schools of thought, as new needs and professions have emerged" [4]. In our approach *an interdisciplinary scientific field represents a transition stage of a new disciplinary field - of a new science*. In this perspective an interdisciplinary scientific field represent a dynamic transformation of a merging disciplinary fields, distinct one against other, regardless the "distance" or the cognitive difference between them, *according with a specific taxonomy or classification*.

Under an accelerate rhythm of change the new requirements arrives not only as a normative pursuit but also as an objective manifestation of new problems. Next to the increasing demand of identification and formulation of those new very complex challenges is shaped also the increasing demand of finding and building of new solutions. On this background, to nominate the issue and possible to "give it a *new name*", to put the "diagnostic" – to locate this new problem in relation with the existing paradigm/theory, to allocate instruments and methods and finally to develop a solution becomes a priority to better describe the structure of the Science in its entire spectrum. This spectrum is a universal alphabet that could join together the universe of scientific research as an activity, the universe of education and the universe of business.

The reality proved that there is an increasing demand for measurement of interdisciplinary and this is requested by:

a. The development and the huge dynamics of new science fields. In research the new interdisciplinary fields of science developed relatively recent, put in a new light the importance of interdisciplinary in new domains like: human adaptive mecatronics (HAM), Mecatronics, Intelligent control, Artificial Intelligence and Intelligent Machine, Cognitive science [5]:

a1. From natural and engineering science to SSH (Socio Sciences and Humanistic Sciences), from research laboratory to new fields of science, the technical progress:

- *Mecatronics* as a technology that becomes a philosophy "determined the shift from traditional *engineering sequential to a simultaneous engineering"* [6]**;**
- *Biomaterials* ("The interdisciplinary and integrative nature of biomaterials science new chemical engineering interdisciplinary field of Biomaterials") with an already

announced revolution brought by the applied science and engineering in view „to serve biological aspects of the human condition and the humans[7]";

- *Nanotechnologies* ("In the simplest terms, the subject of nanoscience technology is defined as the science and technology of the direct or indirect manipulation of atoms and molecules into functional structures, with applications that were never envisioned before" [8]) represents an powerful change source described as „the emerging field of *nanoscience and nanotechnology* is leading to a technological revolution in the new millennium. The application of nanotechnology has enormous potential to greatly influence the world in which we live. From consumer goods, electronics, computers, information and biotechnology, to aerospace defence, energy, environment, and medicine, all sectors of the economy are to be profoundly impacted by nanotechnology." [9]
- „*Integronics* highlight new solutions, integration as: genetic integration, integration by addiction, integration by choice" [10];
- *Other new interdisciplinary fields* as a result of evolution in „future technological development means micromechanics and biomecatronics nanomecatronics" [11];

a2. From SSH science to natural and engineering science as social interactions of the collective dimensions of the technological applications. In the new millennium is prepared the re-evaluation of humanity as "a key element of HAM and the issue of modelling and understanding the human factors in a control loop is receiving great interest in current research. Research into human science under the HAM concept includes psychology, philosophy, neuroscience, linguistics, anthropology, etc." [12]; Maybe more than ever becomes actual the eternal questions of this domain: what is the reality of being human? Or what is reality?

b. the new developments of the *research process and better understanding of the mechanisms of scientific research*:

- new (relatively new**) *research processes organising*** - the professionalization of research: the distinction between research activity, scientific management, knowledge management, knowledge production, knowledge economy, research marketing, etc research projects increasing complexity, overture, duration, cost and budget;
- the *quality and the "amount"* of the new (research results)/ (OSLO, FRASCATI);
- the *geographical spreading of the locations* where is validated, disseminate and protected (IP)) the research activity results is the entire globe "scene";
- the increasing *demand for efficiency* of the research processes. "A high level PhD activity can be carried out only in correlation with the world research dynamics" [13] Technology of science / process of science development - organized process not any more governed by chance or intuition / projecting scientific research/ *strategic management*. Is not any more so randomized .it becomes very oriented and the strategic dimensions and asks a very precise description of the object of study. The research process becomes very expensive and complex structures, involving large teams of researchers from different expertise domains and important resources (budgets). Under the efficiency criteria increases also the need to evaluate the research activity of the researchers institutions/research units performance;
- the need *to integrate the knowledge fluxes* - digital repositories building, efficiency in knowledge access. "Then number of won projects is great which, in turn, results in an impressive scientific production. This academic environment is very adequate for a successful implementation of a digital repository." [14];
- the *new research perspectives* - new research processes representations. In the perspective of Genetic Algorithms representation of the research processes ("possibly by promoting cooperation or competition among the simultaneous evolving populations. This approach is known as cooperative evolution or co-evolution" [15]) then could be identified elements from "cooperative learning strategies" [16] which involves dealing with some issues like: niche definitions, characteristics of concept description, selection of learning problem, selection of the set of operative concept.

c. New developments in **education** the competences building through **technology education,** considering that "one of the goals of technology education is to teach students about the processes and content knowledge pertaining to technology and to equip them with the necessary skills to solve problems through manipulating materials and tools to meet their needs in ways that will be of benefit to society." [17] In this context the interdisciplinary is illustrated by the Technology Education as an integrator of "science, mathematics, technological and environmental knowledge as well as social science content, for example history, economics, sociology and political science" [18].

d. New developments in business - opportunities, dynamics… The business world and society are increasingly ready for sustainability „therefore, dealing with technology and innovation is an essential skill for a manager" [19].

e. The *location of the problem or bottom up approach*, the solutions based upon *local needs that may create opportunities on the global market due to their unique nature*. There are indications in the literature regarding the power of context as a source of innovation, when the identification of societal expectations from technology" [20] becomes a crucial competitive building issue and new opportunities spring allowing that principal scope is to better serve the needs of society. Interdisciplinary orientation as a principle for new programs development - case of bottom up development of IT technologies in African contextualized to the local needs of a society. Need based approach substitute the talent based approach when the relationship individ with technology is strongly differentiated by the background and his technology experience. The situated learning approach is a way to acquire applicable knowledge within a context;

f. The industry as a new "scene" of doctoral programs from

the "traditional model" thorough "introducing PhD researchers into industry, by training them in industry with academic supervision [21] (Denmark and Israel case).

g. "*Category of health and environmental risks calling for interdisciplinary expertise" [22]: of the chemical and nuclear industries, pollution* **(**presence of low levels of dangerous substances in the air, soil or water), radio frequencies, particularly those associated with mobile phones. The "isolated sciences approaches" increase the accumulation of catastrophic risks - regardless the emissions amount because of their cumulative and persistence effect of the "critic mass" formation. One manifestation of a scientific field critic mass formation could be represented by the economic sector activity structuring. But, to any human action there is a reaction, an impact, an effect over the natural systems (environment: earth atmosphere + life systems/plants/animals) but also on social, societal, cultural systems. In the case of mobile phone evaluated as a *social object* becomes visible the interaction between artificial tools, products of applied research and engineering) and all of these systems. Some examples could be: the "*sociocognitive exposure"* with its possible effects "on large populations to be exposed to worrying information.", new human social behavior -Social networks (Facebook, Linkedin, HI5, etc.), new demographic factors (direct influences over mortality and morbidity levels).

II. Doctoral Process – Working Hypothesis

The importance of the doctorate is sustained by the emergence of the knowledge economy and its competitive demands. The knowledge globalization requires a high level of transparency in the doctoral process development.

The doctoral process is organized by an authorized institution (in our case ASE Bucuresti). The entrance of the Phd student in the doctoral process is unique allocated to a unique doctorate scientific field in accordance with the national regulation. The process has two stages. The first one is theoretic (synthesized by the advanced high education program ISCED 6-7 (ASE): specialized disciplines names) and the second is a research oriented one - described by a scientific program (possible to be classified with an (NABS 2007 code). In our approach we consider the research program as a black box. The Phd student could merge and integrate disciplinary fields to create a new, interdisciplinary one.

In this paper we intend to evaluate the probability of development of interdisciplinary field of science as a result of finalized doctoral thesis. We assume that every finalized doctorate thesis can be described by a vector with three dimensions. First dimension is given by the position in the doctoral scientific field taxonomy (at national level), the second is set by the position in the advanced high education program taxonomy (ISCED 6-7) and the third dimension reflects the place occupied in an international scientific taxonomy.

The relative positioning to the frontier of the new in the taxonomy's coordinates offer the opportunity to evaluate the distributions of the probability density for chosen dimensions by application of the Generalized EM and k-Means Cluster Analysis. We have used the module from STATISTICA 8.0. to automatically determine the "best" number of clusters from the data, using v-fold cross-validation techniques.

Our working hypotheses are:

- the professor that coordinates the doctorate have an highly expertise in the field in which coordinate the doctoral program;
- the thesis should be allocated into a specific international taxonomy, with a unique identity by the author himself;
- our analysis is focused on the scientific field perspective ignoring the varieties of organizing schemes (with /without bourse, with/without presence, with/without taxes);
- the previous minimum ISCED 5 (with the First Stage of Tertiary Education finalized [23]) specialization of the doctoral program beneficiary is ignored. Here is possible to develop the same discussion regarding the differences in the background of the educational program field of science in relation with the doctorate scientific field.

The model could use classifications/taxonomies like: at international level - UNESCO nomenclature, OECD's FOS 2007 etc.; at European level: CERIF, CRIS Data Model, Frascati, Cambera and Oslo manuals, NABS 2007; at national level: CIP 2000 - USA, ASRC 2008 - Australia, JACS – United Kingdom etc.

III. Method

In this paper we have used the data base of The Bucharest Academy of Economic Studies regarding the doctoral thesis which was available on-line. The study refers to the first semester of the year 2010.

In view to assess the propensity for interdisciplinary development of the doctoral scientific fields we have identified clusters using the following three variables:

- **codddASE -** the code of doctorate scientific field assigned by the institution that organize the doctorate (ASE) [24] corresponding to first dimension (table 1):

Table 1

codddase	The code of doctorate scientific fiels assigned by the institution that organize the doctorat (ASE) in conformity with the national regulation
1	Business Administration
2	Cybernetics and Economic Statistics
3	Accounting
4	Economics
5	International Economic Relations
6	Finances
7	Economic Informatics
8	Management
9	Marketing
10	Law

- **cod_cod_ASE** – the code of the advanced high education program ISCED 6-7 (ASE): specialized disciplines names (the second semester of the 2009-2010 academic year), corresponding to the second dimension (table 2):

Table 2

codddase	cod_cod_ASE	Advanced high education programme ASE: specialized disciplines names (2009-2010 universitary year)
1	**1**	Business strategies in services
1	**2**	Quality management and excellence in business
1	**3**	Business intelligence systems
1	**4**	Organization and knowledge dynamics in business
2	**5**	Applied mathematics in economics
2	**6**	Multidimensional analysis of data
2	**7**	Games theory
2	**8**	Surveys and polls
3	**9**	Epistemological approaches in accounting and concepts and practices in auditing
3	**10**	Conceptual difficulties and credibility of accounting
3	**11**	Management of the financial-accounting information
3	**12**	Accounting theory and specific practices regarding financial reporting
4	**13**	Qualitative modeling and structuring the research topics
4	**14**	Comparative analysis of the economic systems and models
4	**15**	Regional and rural sustainable development
4	**16**	Dynamics of the economics principles and economic policies
5	**17**	International investments
5	**18**	International trade and financial markets
5	**19**	Risk management in international business
5	**20**	European integration economics
5	**21**	International economics
6	**22**	Insurances economics
6	**23**	Risk and performance on the stock market
6	**24**	Corporate finances
6	**25**	Public finances and public options
6	**26**	Monetary economics
7	**27**	Digital economics
7	**28**	Data basis
7	**29**	Multimedia technologies
7	**30**	Internet and access technologies to the data
8	**31**	Modern approaches in trade management of firms
8	**32**	Organization management
8	**33**	Quality processes management
8	**34**	Strategic management and managerial simulations
8	**35**	Preparing, assessing and auditing of the economic projects
8	**36**	Strategies and policies in human resources management
9	**37**	Integrated marketing communications
9	**38**	Relationship marketing
9	**39**	Advanced marketing models and methods
9	**40**	Marketing activity planning
10	**41**	International trade law
10	**42**	Competition law
10	**43**	Trade law
10	**44**	Labour law

- **UNESCO_teza –** the code of UNESCO nomenclature for fields of science and technology (the 4-digit) [25], see table 3.

Table 3

Selection from UNESCO nomenclature

53	Economic Sciences
5301	Domestic fiscal policy and public finance
5302	Econometrics
5303	Economic accounting
5304	Economic activity
5305	Economic systems
5306	Economics of technological change
5307	Economic theory
5308	General economics
5309	Industrial organization and public policy
5310	International economics
5311	Organization and management of enterprises (see 3310)
5312	Sectorial economics
5399	Other economic specialities
54	Geography
5401	Economic geography
56	Juridical Science and Law
5601	Canon law
5602	General theory and method
5603	International law
5604	Legal organization
5605	National law and legislation
5699	Other juridical specialities
59	Political Science
5901	International relations
6306	Occupational sociology

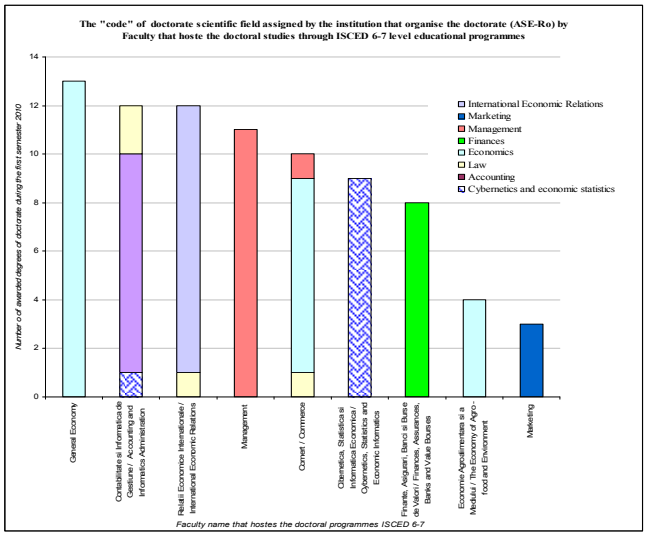


Fig.1 Faculty that hosts the doctoral studies

We consider that the taxonomy realized into the measurement scale reflects:

a. the contiguity of the scientific fields without overlap (Fig. 1);
b. the code number reflects the hierarchical structure of the classification system, in some measure the difference between scientific fields – in our analysis that is used to model this difference into a distance (mainly in UNESCO Nomenclature), see Fig. 2.

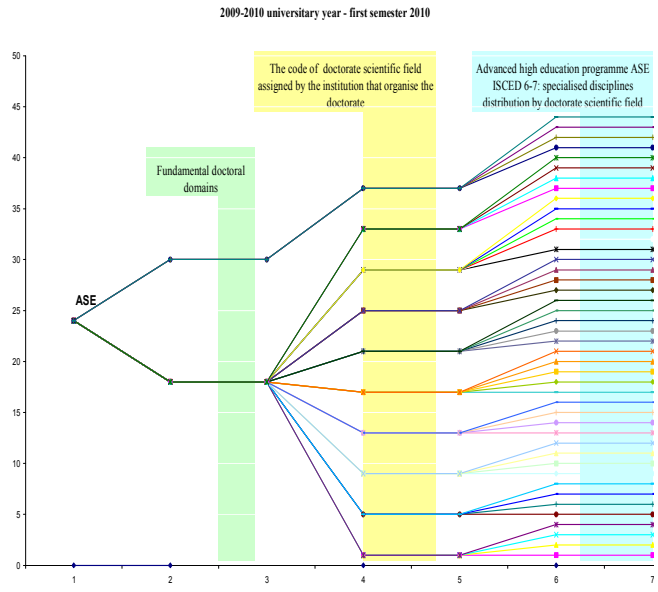


Fig.2 Scientific fields scales overview

"An academic discipline, or field of study, is a branch of knowledge which is taught and researched at the college or university level. Disciplines are defined (in part) and recognized by the academic journals in which research is published, and the learned societies and academic departments or faculties to which their practitioners belong." [26]

"Fields of study usually have several sub-disciplines or branches, and the distinguishing lines between these are often both arbitrary and ambiguous." [27]

We emphasis the opportunities offered by the taxonomies approaches [28] with:

- the allocation to a specific class indicates some common characteristics (possible to be quantified in a controlled manner);
- the possibility to use the evolutionary economic theory approach based on the parents/sons relationship. The advantages of these evolutionary relationships is that every subject is allocated in a unique "taxa" is member of a unique "taxon", in a taxon family tree type, with one or more parents and obvious with an unique identity given by the unique universe created under the chosen classification system;
- there are some limits or discussion issues like:
    - what should be the limits [min; max] of the accepted similarities/dissimilarities between taxa and taxons level or between parents and sons;
    - what should be better system classification for the identified problem;
    - the statistical convergence process request an "common" agreed classification system that should cover the entire universe of the issue;
    - the discussion regarding the procedure to enter into the chosen classification (the allocation procedure)…etc;
    - the flexibility of the classification system from the perspective of the openness to accept new members in " real time" and also the capacity to be connected with others classifications systems (centered on the same problem or on different problems).

We try to detect groups of doctorate scientific fields with distinct similarities regarding the probability density by the continuous variables (codddASE, cod_cod_ASE, UNESCO_teza - scaled by the scales with the same name) distribution for each identified group, through the tool *Generalized EM and k-Means Cluster Analysis* module of *STATISTICA 8.0"* [29]. The expected distributions for every variable (included in the different clusters represent a measure of the interdisciplinary propensity of the doctorate scientific field by groups.

Generalized EM and k-Means Cluster Analysis module *is an* "Analyses of data method" for large datasets, using a "Data mining" tool for unsupervised learning and pattern recognition. Because the dataset (3 variables) doesn't permit to observe the number of real clusters/structures in the data we apply the k-Means algorithm, with the maximizing the initial distances (normalized Euclidean distances) between clusters as a result of the selection procedure in view to differentiate the clusters. The image of maximizing the normalized mean across clusters (for all variables) when there are different from each

other as possible is visible in the figure 3.

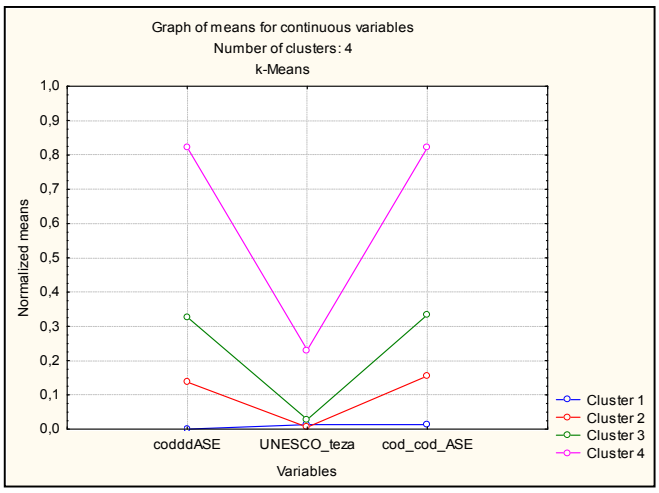


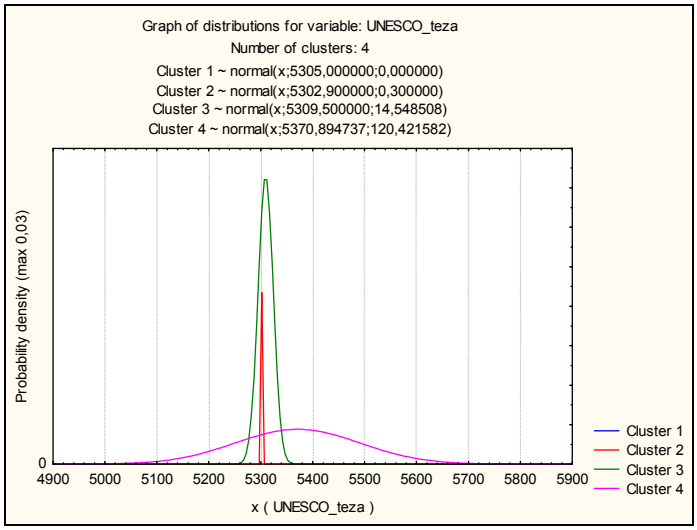
Fig.3 The image of maximizing the normalized mean across clusters

"The observation are assigned to clusters by the" probability of cluster membership based on one or more probability distribution" [30] (here the probabilities distribution for the three continuous variables presented before) and not by maximizing the differences in means for continuous variables (as it happens in the base clustering techniques). "The goal of the clustering algorithm is to maximize the overall probability or likelihood of the data, given the (final) clusters solution" [31]. The final best number of clusters from the current data is the result of the application of "v-fold cross-validation scheme/algorithm".

Among the various options k-means clustering method in the *Generalized EM & k-Means Cluster Analysis* module there is the normalized Euclidean [32] distances between observations and cluster centers. The normalizing transformation remove the differences in the ranges (scaling) for variables, accordingly the fact that the normalize quantities ranges from 0 to 1, regardless the primary range scale.

The Statistica 8.0 program computes probabilities for each observation to belong to each of the clusters based on the chosen distribution (the normal distribution by default).

The measure of the interdisciplinary propensity of the doctorate scientific field by groups, as a synthesis of the figure 4, is presented in the table 4, where the doctorate scientific field is allocated into the clusters differentiated by the variance of the scientific fields (described by the tree mentioned variables).



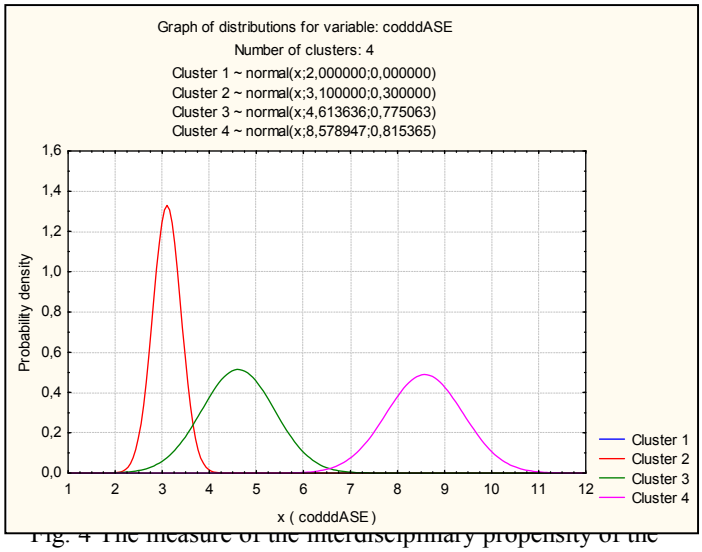


Fig. 4 The measure of the interdisciplinary propensity of the doctorate scientific field by groups

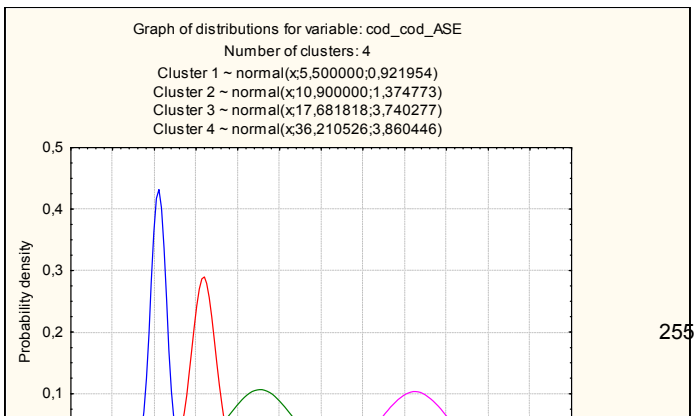


Table 4

	Between	df	Within	df	F	p value
codddASE	2466,01	3	40,0	79	1624,9	0,00
UNESCO_teza	2351110878,09	3	284839,7	79	217359,4	0,00
cod_cod_ASE	40140,26	3	926,1	79	1141,4	0,00

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Overall
Minimum	5,000	9,000	14,000	31,000	5,000
Maximum	8,000	13,000	25,000	43,000	43,000
Mean	5,500	10,900	17,682	36,211	19,639
Standard deviation	0,972	1,449	3,784	3,966	110,673

Under the mentioned limits, there are visible some interpretation. The doctorate scientific field with the highest propensity to develop through interdisciplinary new scientific field is Law, followed by Marketing and on the third place with management. The doctorate scientific field with the highest degree of specialization is the Cybernetics and economic Statistics followed by accounting and in a small range by economics.

Table 5

Hierarchy by distance to centroid_CGA_kE / cluster

The code of doctorate scientific field assigned by the institution that organise the doctorate (ASE)	CGA_K_euclidian-cat	
Cybernetics and economic statistics	cluster1	minim variance of scientific field
Accounting	cluster2	
Economics	cluster2	
Economics	cluster3	
International Economic Relations	cluster3	
Finances	cluster3	
Management	cluster4	
Marketing	cluster4	
Law	cluster4	maxim variance of scientific fields

IV. Conclusions

Under an accelerate rhythm of change the new requirements arrives not only as a normative pursuit but also as an objective manifestation of new problems. Next to the increasing demand of identification and formulation of those new very complex challenges is shaped also the increasing demand of finding and building of new solutions. On this background, to nominate the issue and possible to "give it a *new name*", to put the "diagnostic" – to locate this new problem in relation with the existing paradigm/theory, to allocate instruments and methods and finally to develop a solution becomes a priority to better describe the structure of the Science in its entire spectrum. This spectrum is a universal alphabet that could join together the universe of scientific research as an activity, the universe of education and the universe of business.

In view to improve the research quality in a more globalised environment is requested to define and describe in a international specialized taxonomy the processes/activities, results (papers/dissertation presentations), research projects, educational ISCED 6-7 programs that make a contribution to the scientific doctorate process development finalized with a doctoral thesis, a presented public dissertation respectively with a doctoral title awarded.

The advantage of this costly process is that in consequence of positioning in an international coordinates is possible to improve the description and better understanding some essential processes that influence the quality of academic research/doctoral scientific research, processes like:

- allowing the entrance of the doctoral scientific research (doctoral dissertation/paper) into the international knowledge fluxes (the possibility to evaluate and compare every thesis in a global environment);
- increasing the academic/doctoral scientific research activity and its results visibility;
- actively contributing to the new knowledge thesaurus developments;
- becoming available, accessible (easy to be cited) and connected to the main scientometric systems;
- relatively positioning against the frontier of the "new" defined by the international system of reference;
- the huge importance of this allocation sustains the fact that the author thesis should allocate this code under the validation its supervisors.

The expected distributions for every variable (included in the different clusters as a measure of the interdisciplinary propensity of the doctorate scientific field could offer an valuable resource in projecting the interdisciplinarity of the doctoral educational program (ISCED 6-7) and maybe the flexibile determination of the doctoral scientific fields inside the fundamental doctoral domains.

All this issues raises a lot of problems at European, national and University/Institution levels, at organization, administration and functioning of doctoral processes. One way to increase the competitivity of academic research is to increase its comparability (in a static perspective) and also to estimate its degree of interdisciplinarity (in a dynamic perspective).

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[32] Euclidean distance

$$(x,y)=DE=\sqrt{\sum_i (x_i'-y_i')^2},$$

calulate with normalised values:
xi'=(xi-ximin)/(xmax-xmin)
yi'=(yi-yimin)/(ymax-yamin)
where , x_{min} and x_{max}, and y_{min} and y_{max}, are the minimum and maximum values for the x and y variable in each distance. (see STATISTICA 8.0 Help)