Certain Approaches to Automated Designing of Competence-Oriented Models for Knowledge Engineers Using the Tutoring Integrated Expert Systems

Rybina G.V., Fontalina E.S., Sorokin I.A.
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
Moscow, Russian Federation
galina@ailab.mephi.ru

***Abstract*—The development of engineering knowledge led to the emergence of new professions, which are widely popular professional competence and personal qualities. This paper provides a methodological and technological experience in automated construction competence-oriented models specialists in the field of knowledge engineering, in particular, specialists of the profession "system analyst" with the use of tutoring integrated expert systems.**

***Keywords*—tutoring integrated expert systems, competence-oriented model of a specialist, engineer knowledge, student model, AT-TECHNOLOGY workbench.**

I. Introduction

Implementation of advanced concepts of transition to new professional tutoring and training computer-aided technologies for IT professionals implies a flexible common use of professional educational standards and the automated designing technology for the intelligent tutoring systems (ITS), in particular, tutoring integrated expert systems (IES) of various architectural types [1], [2]. It is ITS architectures that procure the advanced tools of the students' intelligent tutoring, monitoring and testing and help shape the competence-oriented models for future professionals [1] as the ultimate result. It is noteworthy that the competence format of the new Federal State Educational Standard for Higher Professional Education [3] envisages that the professional education quality should be assessed based on the graduate's competencies meaning the integral result shown after the education plan completion. The young professional's competencies shall enable him or her to successfully work in the selected occupation area and acquire social, personal and general cultural qualities that promote his/her social mobility and sustainability on the labor market.

In terms of the European Educational System, the notion of "competence" includes, besides the cognitive, operational and technological component, incentive, ethical, social and behavioral components that determine the system of the graduate's values as well [4]. Thus, as concerns the knowledge, skills and capacities widely used in the current Federal State Educational Standard for Higher Professional Education, the competence-oriented models for professionals of different levels have a comprehensive, integral nature that includes the set of knowledge, skills, capacities and social and personal qualities [5]. Accordingly, graduates' competencies improve in case of gradual completion of bachelor and master educational programs.

The key problem is to make sure that the professional standards, in this case IT standards, will not remain a certain methodical basis, but will be pro-actively included in the automated shaping of future professionals' competencies that show what the student will know (i.e. the student's theoretical training) and be able to do (i.e. ability to leverage theoretical knowledge in addressing practical tasks) upon completion of a certain educational plan (direction) and how well he or she is able to apply the knowledge, skills and personal qualities gained at the university for successful professional activity.

Similar experience has already been gained in the Cybernetics Department of MEPhI when training professionals in Applied Mathematics and Informatics, which is currently pro-actively used as part of the Software Engineering direction. This was facilitated by the research and development project of creating the intelligent technology for building a broad TIES category, including tutoring IES and web-IES [1], [2], [6].

The problem-oriented methodology of TIES designing [1], [2] and its supporting unique workbench type tool, AT-TECHNOLOGY workbench, enable the development of state-of-the-art IES and web-IES with advanced intelligent tutoring, monitoring and testing tools for students, through designing and software support to the individual competence-oriented models of students (with the view to the personality's psychological profile), adaptive tutoring models and explanations, models of course/discipline ontologies. etc. The main provisions of the problem-oriented technique and the description of functional options of various versions of AT-TECHNOLOGY workbench are available in several monographs and numerous papers, e.g. [1], [2], [6] etc.

In order to implement intelligent tutoring based on designing and use of tutoring IES and web-IES in the training

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process, the professional standards for Information Technologies [5] were rather efficiently used as the basic information methodical resources when designing professional competence models, in particular, for such occupations as "programmer", "system analyst", "IT system specialist", "system architect" etc.

Such occupations as "system analyst", the demand for which is coming closer to that for programmers in the contemporary market for high information technologies, should be specially designated among the listed professions. At present, these professionals in knowledge and technologies of designing intelligent systems are called differently: knowledge engineers, knowledge analysts, cognitologist engineers, task setters, and much attention is paid to their training. For instance, the systemic view of training the knowledge engineers is available in [7], [8] where the authors' experience in training knowledge engineers and business analysts in the last 15 years is summarized. Many interesting findings on this problem are available in [9], [10], [11], [12], [13], [14] and other papers.

In general, as the experience of development and use of tutoring IES and web-IES in training suggested, the following objectives are the critical in shaping the professional and general competences are:

- Selective sampling at each tutoring stage (bachelor, master) of the knowledge, skills and capacities that the students must gain (applied course/discipline ontologies, generalized ontologies of individual training fields are used);
- Improvement of the monitoring and testing techniques, both for the purpose of shaping of current competence-oriented models for students and upon tutoring completion (web-testing of the students with generation of options based on the genetic algorithm is used);
- Efficient accounting for personal features of the students in selecting and shaping of the learning strategies and impacts, including the development of special corrective training impacts intended to develop the student's individual personal features (the students' psychological testing findings together with different types of learnings interactions are used);
- Use of additional (repeated) tutoring based on the identified gaps in knowledge and skills etc. (applied in the aggregate of tutoring relations for different students' clusters).

As concerns the information required for shaping the social and personal competencies (from the group of general competencies) that take into account the students' personal features, here we can partially make use of the information provided in professional standards in the Self-Development job description for each specialization [3]. In addition, in order to identify the personal features, there exists a great number of psychological tests, questionnaires, special websites etc. For instance, in the context of IES and web-IES [1], [2], [6], the option of detecting approx. 20 personal qualities and their correlation with an individual tutoring model was implemented. The main problem here is to find and select the expert information that signals the degree, in which each particular competence is displayed for each of the personal features.

It is noteworthy that there is no general classification of competencies now, but the designation of professional and versatile competencies is a generally acceptable point of view. Further specification depends on the specific features of the profession, the traditions of the university that trains professionals in this domain and other particular features.

This paper is intended to review the methodical and technological experience in automated designing and use of tutoring IES and web-IES of competence-oriented models for future knowledge engineers ("system analyst" profession).

II. The dynamic designing of competence-oriented models for future professionals based on the review of the monitoring of IELS students' functioning processes

Tutoring IES and web-IES developed in the laboratory of "Intelligent Systems and Technologies" of the Cybernetics Department of MEPhI have been pro-actively used since 2008 for automated support to basic courses and disciplines in such fields as Applied Mathematics and Informatics and Software Engineering, in particular: Introduction in Intelligent Systems, Intelligent Dialog Systems, Dynamic Intelligent Systems, Designing the Knowledge-Based Cybernetic Systems, Modern Intelligent System Architectures, Intelligent Information Systems.

For all of these courses and disciplines, the applied ontologies were implemented and are dynamically supported using AT-TECHNOLOGY workbench basic tools. The ontologies jointly form the generalized ontology of Intelligent Systems and Technologies as the tutoring and methodic basis for training knowledge engineers. Significant methodological and technological experience was gained in automated maintenance of a significant number of individual models for the students in the above disciplines (over 2,500 models) and the appropriate tutoring models, the joint analysis of which enables forecasting so-called "perfect" model of a young professional, in particular, a systemic analyst (knowledge engineer).

The possibility of such forecast implementation is largely determined by the particular features of development and use of tutoring IES and web-IES related to automation of virtually all processes arising during tutoring and control of students' knowledge/skills. The entire information about the students, course/discipline topics, academic progress, students' monitoring results, individual recommendations based on the academic progress etc. are in the single environment and at any time available to the student and/or the academic progress supervisor, which is achieved by special monitoring tools for IELS students' functioning process.

Pursuant to [2] and other papers, IES functioning is monitored from two angles. One of them is related to the role and part of tutoring IES in terms of tutoring management at the university, i.e. the use of IES for support of basic tutoring stages: holding of classes (lectures, workshops, laboratory work), holding of regular inspections, both during tutoring and at tutoring control points envisaged in the curricula of a certain course/discipline, as well as control efforts as part of credits and exams.

Another aspect is the review of a set of functional objectives typical of intelligent tutoring. Addressing the basic intelligent tutoring problems has been reviewed in various papers [2], [6] etc. many times; so, let's note that, in the context of summarized ontology of Intelligent Systems and Technologies and shaping the single ontological knowledge and skills space, we have managed to virtually implement the full set of functional objectives typical of the intelligent tutoring technology, namely [2], [6] etc.:

- Individual planning of the method to study the specific training course (specification of the personal tutoring trajectory/strategy based on the course/discipline ontologies, customized monitoring and identification of "gaps" in students' knowledge and skills, enhancement of individual tutoring with reference to the student's psychological profile, etc.);
- Intelligent analysis of solutions to training objectives (simulation of reasonings of the students who address training objectives of different type, in particular, using non-formalized techniques; identification of error types and reasons for their manifestations in knowledge and skills, instead of stating them; feedback via dynamic updates of the students' knowledge and skills; forecast of exam grades etc.);
- Intelligent decision support (use of the conventional expert system (ES) technology and IELS technology for intelligent support at each stage of addressing tutoring tasks, including the expanded explanations of How? and What? type, selection of the solution options, prompt of the next solution stage etc.)

Thus, the monitoring of tutoring IES and web-IES functioning in this case is associated with "tracking" and review of all processes of shaping the student's individual model for each student for a particular discipline by identifying the current knowledge/skills level using web testing and other methods, as well as by shaping the psychological profile of the student's personality as an important component of the student's model.

It is noteworthy that, according to the problem-oriented methodology, the dynamic comparison of web testing findings with the respective fragment of applied course/discipline ontology forms the basis of the approach to designing the student's current competence-oriented model. The result is so-called "problem zones" [1], [2] in students' knowledge in individual sections/subsections and designing of the current competencies that jointly reflect the state of the student's model not only in terms of knowledge level but also by shaping the conceptual and technological link with the elicitation of the ability to solve certain types of educational unformalized objectives recommended in [15] or educational items on knowledge engineering, e.g. [8]. It is also necessary to constantly draft the lists of students (cohorts) with high and/or low knowledge/skills, conduct systemic statistical data processing and also generate current and final reports (lists) for departments and dean's offices.

The final term logs that reflect the students competence-oriented models contain comprehensive information on the students: their grades received during control efforts (exams, credits, tests) intended to elicit the level of knowledge and skills, the current professional competencies, information on the psychological testing passing, information on independent work, the final grade forecast, and include the actual grade received in the exam (the logs are issued for all students trained in a particular course/ discipline).

Analytical and statistical processing of tutoring IES application efficiency is critical for shaping the future professional's model. By introducing special parameters describing an individual student and a certain cohort (cluster) of students These parameters were derived expertly, based on the review of a rather representative data volume (approx. 2,000 students' models), and largely target the basic structure of the student's model [1], [2], the components of which are: student's knowledge model, student's skills model, psychological profile, competencies model and other components)

The experience suggests that the parameters (indicators) shaped as a result of [2], [6] were the most sought of in terms of designing the competence-oriented models for future professionals.

- Review of "problem zones" for each student for particular courses/disciplines and their clusterization;
- Individual tutoring planning (typology and succession of training impacts; influence of training impacts on knowledge upgrading; search for the most efficient training impacts);
- Calculation of the correlation between the current knowledge and skills levels for the appropriate course/ discipline topics
- Account for the student's psychological profile (personal degree of achievement of target competencies for specific courses/disciplines etc.)
- Exam grade forecast based on academic progress (review of the reasoning when addressing particular educational and training tasks)

Besides, use a whole series of parameters for information processing for the entire students' cohort (group, flow, etc.) namely: aggregate analysis of "problem zones" for specific courses/ disciplines and their clusterization; estimate and clusterization of individual tutoring plans for specific courses/ subjects; exam session result forecast (the link between knowledge and skill level and exam grade by course; review and clusterization of students' psychological types, etc.)

Now let's look at practical examples of designing the "perfect" model of a graduate specialist in systemic analysis field (knowledge engineer) according to the base competencies of the current Federal State Educational Standard for Higher Professional Education in a greater detail.

III. Particular features of training knowledge engineers based on use of tutoring IES

The successes of knowledge engineering in development of models and methods for knowledge transfer from different knowledge sources into a software, called the expert system (ES), and in a wider sense, the knowledge-based systems (KBS) [2], [6], [8], [15] resulted in a new occupation that requires not only professional competencies but also individual personal features. Thus, training of knowledge engineers implies not only gaining professional knowledge, skills and capacities in development (KBS) (ES) but also without regard to his or her psychological profile.

Let's provide some examples from the experience of practical application of tutoring IES and web-IES in the training process at MEPhI, with the emphasis on the technology for automated shaping of the competence-oriented model for a knowledge engineer, with reference to the set of training plans and the generalized ontology of Intelligent Systems and Technologies in Software Engineering training domain.

A. Shaping the specialists' professional competencies

According to the Federal State Educational Standard 3+, the two following competencies are used as the base ones for training knowledge engineers:

- PK-1 is the formalization capacity in his or her subject area, with the view to the limitations on study methods in use;
- PK-2 is the readiness to use methods and instrumental means of study of professional business items

Achievement of these target competencies is facilitated by the common ontological space of knowledge and skills formed out of applied course/discipline ontologies of several tutoring IES and web-IES [2], [6]. It is noteworthy that the general competencies model that is the component of the basic ontology model in the shape of the semantic network [2], in the applied course/ discipline ontologies, is represented as the hierarchy of the discipline/ problem-oriented private competencies (with weight ratios) that reflect the methods of teaching some specific courses.

Table I shows the examples of specification of basic target competencies of PK-1 and PK-2 according to the ontology of the Introduction to Intelligent Systems course based on [15].

Let's briefly look at certain approaches to elicitation of individual professional competencies. Section 1 has already emphasized the particular features of elicitation of students' knowledge in control efforts (exams, tests, credits) by dynamic shaping of the student's current competence-oriented model that is based on the answers to special web tests and subsequent comparisons with the fragment of course/discipline ontology [2], [6].

Now, we emphasize the problems of elicitation of the skills in application of theoretical knowledge in practical sessions. As the experience suggested, training of knowledge engineers implies learning the skills and capacities in solving practical tasks related to the ability to build the simplest situation models in the problem domain based on the "self-expert" principle, proceeding from products, frames and semantic networks [8], [15].

Table I

Examples of specification of target competencies PK-1 and PK-2

PK1	Ability to formalize his or her subject area, with the view to the limitations on study methods in use
PK11	Know and be able to use the systemic analysis methods to assess whether the intelligent system technology is acceptable or not
PK12	Know and be able to select the knowledge presentation models for designing specific intelligent systems
PK13	Possess the skills in simulating reasoning and building-up modern problem solvers (output mediums) for intelligent systems
PK14	Know the principal types of non-formalized problems and be able to design models and methods for solving non-formalized problems of different types
PK15	Know the methods of gaining knowledge from different knowledge sources (experts, texts, databases) and be able to apply them in practice
PK16	Know and be able to apply the modern methods for intelligent systems (imitation, evolutionary, neuro-network, unclear etc.)
PK2	Readiness to use methods and instrumental means of study of professional business items
PK21	Know the main architectures of static, dynamic, integrated and hybrid intelligent systems and be able to design and develop them
PK22	Know the methods of designing knowledge bases for different problem/ discipline areas
PK23	Know the composition and structure of the main tools and be able to reasonably select and apply them when implementing different intelligent systems
PK24	Master the basic methods in designing, development, testing and support of specific intellectual system classes

Thus, when designing the tutoring IES, we created and tested during the training process at MEPhI and other universities the special software that implement the "manual" techniques of addressing non-formalized objectives (non-formalized problems), in particular, those shown in [2], [15]. For instance, to elicit the competencies of PK1, PK11, PK12, PK13, PK14, PK15, PK16, etc. types as listed in Table 1, simulation of the reasoning of the students who solve four types of such non-formalized problems as [6] is used: simulation of the strategies of direct/ reverse reasoning in IES (PK13, PK14, PK15), simulation of simplest situations of the problem domain with the use of frames and semantic networks (PK12, PK13) etc.

Figure. 1 shows the fragment of the applied ontology, Introduction to Intelligent Systems, which comprises: Network Models of Knowledge Presentation, Frames, Frame Definition, Theoretical and Multiple Frame Description, Notion of Frame Prototype and Frame Copy, Homogeneous and Heterogeneous Frame Networks, LKP (language of knowledge presentation) based on frames, Release on Frames Such competencies as PK12 and PK13, which make part of the target competence PK1, are referred to this course/ discipline ontology fragment.

In order to elicit the competencies of PK-2 type, the laboratory practicums and practical knowledge related to the

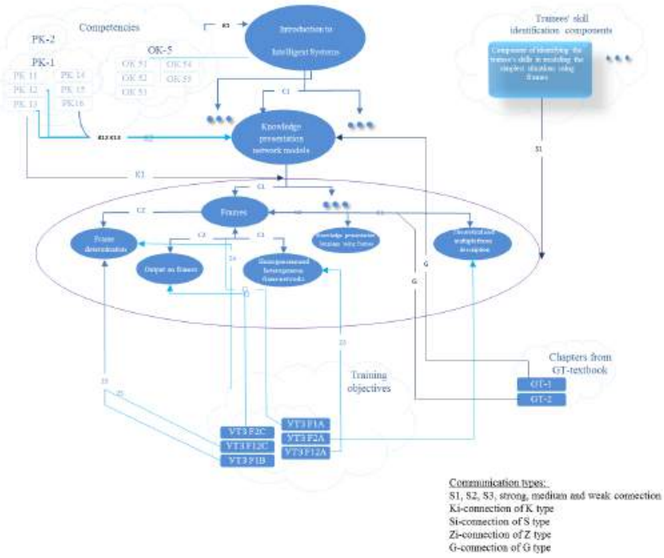

Figure 1. Introduction to Intelligent Systems ontology fragment

instrumental and technological aspects of training knowledge engineers and those oriented on study of the designing technology (KBS) (ES) using the modern arsenal of instrumental tools [2], [6], [15] are used.

Thus, using the Introduction to Intelligent Systems ontology and special means related to building up the student's current models, a certain set of professional requirements (criteria) to competencies of a future knowledge engineer is dynamically created. Table II and Table III contains a set of basic criteria for automated designing of a future specialist's professional competencies (with the recommended expert weights / ratings of each criterion under a 10-score scale) [2]

Now, let's look at the shaping of general cultural competencies and the psychological portrait of a future knowledge engineer

B. Shaping the psychological profile of a future knowledge engineer (in the context of general cultural competencies)

As shown in [15], psychological aspect is critical for knowledge engineering, which is related to knowledge extraction processes, because this particular aspect determines if the knowledge engineer can successfully and efficiently liaise with the knowledge source, the expert. In modern papers, e.g. [2], [7], [8], [15] etc., the suggestion is to take into account a series of personal features or their set as the psychological profile in determination of the so-called "perfect" couple, the knowledge engineer and the expert, to arrange for collective work in creation of the problem area model.

For these purposes, almost two dozens of various author texts are currently used in tutoring IES and web-IES, and the most appropriate test configuration for psychological tests of students depending on the identified competence type is determined using the psychological test generator.

Table II
BASIC REQUIREMENTS TO A FUTURE KNOWLEDGE ENGINEER

s/r #	Requirements	Rating weight
1. Do you have	Broad general scientific training	
	Acquaintance with the reviewing, annotation and other text processing methods	3
	Mastery of quick reading skills	3
	Knowledge of textological methods of deriving knowledge	3
2. Do you know	Acquaintance with the reviewing, annotation and other text processing methods	3
3. Do you master	Mastery of quick reading skills	1
4. Do you know	Knowledge of textological methods of deriving knowledge	9
5. Do you have	Basic training in information sources	
	Qualified knowledge of the methods of knowledge acquisition from different knowledge sources	8-9
	Qualified knowledge of models and methods of knowledge presentation in information sources	8-9
	Qualified knowledge of knowledge processing methods in information sources	8-9
	Qualified knowledge of the systemic analysis basics	8-9
	Mastery of basic information structuring methods	8-9
	Cluster analysis	8-9
	Hierarchical clusterization	8-9
	Designing weighted situations	8-9
	Ranking the selection trees	8-9
	Repertoire grid analysis	8-9
	Possession of KBS (ES) development methods	8-9
	Qualified knowledge of instrumental tools of KBS (ES) designing	8-9
	Holding the practical computer skills, one or several programming languages	8-9
6. Do you master	Qualified knowledge of the methods of knowledge acquisition from different knowledge sources	
	Communications methods	7
	Textological methods	5
	Methods of knowledge acquisition from the database	6
7. Do you master	Qualified knowledge of models and methods of knowledge presentation in information sources	
	Logical models	5
	Inferential	1
	Inductive	1
	Other	1
	Heuristic models	8
	Network	8
	Frames	7
	Semantic networks	5
	Other	3
	Production	8
	Other	3
8. Do you master	Qualified knowledge of knowledge processing methods in information sources	
	Direct or reverse conclusion	8
	Analogy/ precedent based conclusion	5
	Other	3
9. Do you know	Qualified knowledge of the systemic analysis basics	5
10. Are you experienced in	Qualified knowledge of instrumental tools of KBS (ES) designing	9

Table III
BASIC REQUIREMENTS TO A FUTURE KNOWLEDGE ENGINEER

s/r #	Requirements	Rating weight
11. Do you master	Mastery of basic information structuring methods	
	Multiple scaling	5
	Hierarchical clusterization	3
	Designing weighted situations	3
	Conclusion tree ranking	5
	Repertoire grid analysis	5
	Other	3
12. Are you experienced in	Possession of KBS (ES) development methodologies (stages, life cycle, etc.)	7
	Prototyping strategy mastery	8
13. Do you master	Holding the practical computer skills, one or several programming languages	8
14. Do you know	Knowledge of cognitive psychology elements	
	Methods of representing notions and processes in human memory	5
	Main thinking principles (logic, associativity)	5
	Thinking activation methods	5

In terms of the Federal State Education Standard 3+, to shape a knowledge engineer's psychological profile, the following target competencies are the most suitable out of general cultural competencies:

- OK-3, the ability to communicate verbally and in writing in Russian and foreign languages to solve the tasks of inter-personal and inter-cultural communications;
- OK-4, the ability to work as part of a team, by perceiving social, ethnic, confessional and cultural differences with tolerance;
- OK-5, ability to self-manage and self-educate.

However, the use of automated methods for elicidation of the above OK-3, OK-4 and OK-5 competencies is an understudied problem now. There are virtually no papers on establishing the explicit connections between individual personal features of a student's psychological profile and the general cultural competencies. Therefore, as part of taught IELS and web IELS, a cycle of studies intended to specify, in particular, the competencies of OK-4, because the experience related to analysis and clusterization of the students' psychological types has been gained here, and psychological tests are carried out, with the view to the personal degree of achievement of target professional competence of a knowledge engineer.

IV. CONCLUSION

Thus, the methodical and technological experience gained in training professionals in Applied Mathematics and Informatics and Software Engineering in the domain of automated designing using tutoring IES and web-IES of competence-oriented models of knowledge engineers enable to promptly and efficiently review, adjust (based on the cutting-edge innovations in the professional area) and forecast the level and quality of the graduate professionals' cohort. Such approach does not lay down the new foundations only in relations with employers and potential customers only, but also enables planning of the target training of specialists in various fields among undergraduates.

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НЕКОТОРЫЕ ПОДХОДЫ К АВТОМАТИЗИРОВАННОМУ ПОСТРОЕНИЮ КОМПЕТЕНТНОСТНО-ОРИЕНТИРОВАННЫХ МОДЕЛЕЙ ИНЖЕНЕРОВ ПО ЗНАНИЯМ С ИСПОЛЬЗОВАНИЕМ ОБУЧАЮЩИХ ИНТЕГРИРОВАННЫХ ЭКСПЕРТНЫХ СИСТЕМ

Рыбина Г. В., Фонталина Е. С., Сорокин И. А.
Национальный исследовательский ядерный университет МИФИ, Москва, Россия

Развитие инженерии знаний привело к появлению новой профессии, в которой активно востребованы как профессиональные компетенции, так и индивидуальные качества личности. Проанализирован методический и технологический опыт автоматизированного построения компетентностно-ориентированных моделей специалистов в области инженерии знаний, в частности, специалистов по профессии "системный аналитик с использованием обучающих интегрированных экспертных систем.