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Personalised Learning Methods and Activities for Computer Engineering Education*

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This paper aims at establishing interconnections between Felder-Silverman learning styles model (FSLSM) and inquiry-based learning (IBL) activities. FSLSM model is known as the most suitable for engineering education and e-learning. IBL are known as very helpful for students while studying STEM (Science, Technology, Engineering and Mathematics) subjects incl. Computer Engineering. Interconnections are established using expert evaluation method based on trapezoidal Fuzzy numbers. Evaluation was performed by mascil project's teachers-experts in computer engineering. The established interconnections are useful while creating suitable IBL-based learning scenarios for students having different learning styles. These learning scenarios could be created using ontologies-based recommender systems for computer engineering education and STEM subjects using created interconnections.

Keywords: computer engineering education; STEM subjects; Felder-Silverman learning styles model; inquiry-based learning; expert evaluation; trapezoidal Fuzzy numbers; mascil project

1. Introduction

1.1 Personalised learning

The "one size fits all" approach no longer works in education. The authors strongly believe that future school means personalisation plus intelligence [1].

According to [1], learning personalisation means creating and implementing personalised learning paths (scenarios) based on recommended systems and personal learning environments suitable for particular learners according to their personal needs. Educational intelligence means application of intelligent technologies and methods enabling personalised learning to improve learning quality and efficiency.

In personalised learning, first of all, integrated learner profiles (models) should be implemented. After that, ontologies-based personalised recommender systems should be created to suggest learning components (learning objects, activities, methods, tools, apps etc.) suitable to particular learners according to their profiles. Thus, personalised learning paths could be created for particular learners for each topic according to curriculum, e.g. for Computer Engineering and STEM Education. A number of intelligent technologies should be applied to implement this approach, e.g. ontologies, recommender systems, intelligent agents, multiple criteria decision making models, methods and tools etc. to evaluate quality and suitability of the learning components etc. [1].

This approach could be implemented by the following steps:

- Creating learners' models (profiles) based on their learning styles and other particular needs.
- Interconnecting learners' models with relevant learning components (learning content, methods, activities, tools, apps etc.).
- Creating corresponding ontologies.
- Creating intelligent agents and recommender systems.
- Creating and implementing personalised learning scenarios (e.g. for Computer Engineering Education).
- Creating educational multiple criteria decision making models and methods [1].

Learning styles are the main component of students' learner profiles (models). Learning style designates everything that is characteristic to an individual when she/he is learning, i.e. a specific manner of approaching a learning task, the learning strategies activated in order to fulfil the task. Learning styles represent a combination of characteristic cognitive, affective and psychological factors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment [2]. Learning styles model systems differ in several aspects: underlying learning style model, diagnosing method (implicit or explicit), modelling techniques (rule-based approach, data mining, machine learn-

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ing techniques), number of modelled student characteristics besides learning preferences (knowledge level, goals) and the type, size and conclusions of the reported experiments [1].

Ontologies and recommender systems should be based first of all on established interconnections between students' learning styles and aforementioned learning components. While establishing those interconnections, high-quality learning styles models and vocabularies of learning components should be used, on the one hand, and experienced high-quality experts should participate in this work, on the other.

Personalised learning issues and application of intelligent technologies in education are of high interest for the researchers [3–5].

The aim of the paper is to present created interconnections and ontologies of Felder-Silverman learning styles [6] and inquiry-based learning (IBL) activities [7–12] for computer engineering education.

1.2 Felder-Silverman learning styles model

Felder-Silverman learning styles model (FSLSM) [6] is known as the most suitable for engineering education. According to [6], "students learn in many ways—by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorising and visualising and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching method also vary".

A learning style model classifies students according to where they fit on a number of scales pertaining to the ways they receive and process information [6].

Felder and Silverman propose that a student's learning style may be defined by the answers to five questions:

1. What type of information does the student preferentially perceive: sensory (external)—sights, sounds, physical sensations, or intuitively (internal)—possibilities, insights, hunches?
2. Through which sensory channel is external information most effectively perceived: visual—pictures, diagrams, graphs, demonstrations, or auditory—through words or sounds?
3. With which organization of information is the student most comfortable: inductive—where facts and observations are given, and underlying principles are inferred, or deductive—where principles are given, and consequences and applications are deduced?
4. How does the student prefer to process information: actively—through engagement in physical activity or discussion, or reflectively—through introspection?
5. How does the student progress toward understanding: sequentially—in continual steps, or globally—in large jumps, holistically?

1.3 Inquiry-based learning

Inquiry-based learning (IBL) has become popular in school education in recent years. The IBL definitions are presented by various aspects in scientific literature:

> "The creation of a classroom where students are engaged in essentially open-ended, student-centred, hands-on activities" [7].
>
> "Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse, and interpret data; proposing answers, explanations and predictions; and communicating the results" [8].
>
> "Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations and scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" [8].

Inquiry is referred to the science education literature to designate at least three distinct but interlinked categories of activity: (a) what scientists do when they use scientific methods, (b) how students learn (by pursuing scientific questions and engaging in scientific experiments by emulating the practices and processes used by scientists); and (c) a pedagogy, or teaching strategy, adopted by science teachers when they design learning activities, which allow students to observe, experiment and review what is known in light of evidence [9].

In terms of learning, the inquiry-based approach is about engaging students' curiosity in problems in the world and the ideas that surround them. In the workplace, this might mean observing and posing questions about situations. If their questions are too complex, they may try to simplify or model the situation. They may then try to answer their questions by collecting and analysing data, making representations and by developing connections to their existing knowledge. They then try to interpret their findings, checking that they are accurate and sensible, before sharing their findings with others. This process is often missing in the school classroom because the teacher often points out what must be observed, provides the questions, demonstrates the methods to be used and checks the results. Students are merely asked to follow the instructions [10].

This definition is often used jointly with the five

Table 1. FSLSM (according to [6])

Sensory	INFORMATION TYPE	Intuitive
Concrete, practical, oriented towards facts and procedures	⟷	Conceptual, innovative, oriented towards facts and meaning.
Sensors like facts, data, experimentation, and solving problems by standard methods, but dislike surprises. They are patient with detail, but do not like complications. Sensors are good at memorizing facts, and tend to be careful and slower in completing their work.	An important distinction between intuitors and sensors is that intuitors are more comfortable with symbols. Since words are symbols, translating them into what they represent comes naturally to intuitors and is more of a struggle for sensors.	Intuitors prefer principles, theories, and innovation, but dislike repetition. Detail may bore them, and they welcome complications. Intuitors are good at grasping new concepts, and they tend to complete tasks quickly, which on occasion, may lead to carelessness.
Visual	SENSORY CHANNEL	Verbal
Prefer visual representations of presented material – pictures, diagrams, flow charts	⟷	Prefer written and spoken explanations
Visual learners remember best what they see: pictures, diagrams, flow charts, time lines, films, demonstrations. They may forget information that is communicated to them verbally.		Verbal learners remember much of what they hear and even more of what they hear and then say. They remember and learn well from discussions, prefer verbal explanation to visual demonstration, and learn effectively by explaining things to others.
Active	INFORMATION PROCESSING	Reflective
Learn by trying thins out, working with others	⟷	Learn by thinking things through, working alone
Active Learners do not learn much from lectures because they require them to receive information passively. They work and learn better in situations that allow for group work and hands on experimentation.	The complex mental processes that convert perceived information into knowledge consist of two categories: active experimentation and reflective observation. Active experimentation involves doing something with information in the external world, such as discussing it, explaining it, or testing it in some way. Reflective observation involves examining and manipulating the information introspectively. The opposite of active is passive, not reflective. This consideration is within the context of student participation in class. They explain that active signifies that students are doing something other than listening and watching in class, and that active student participation will encompass the learning processes of both active experimentation and reflective observation.	Reflective Learners require situations that provide opportunity to think about the information being presented. They work well alone or in a one-on-one situation with another person and when given the opportunity to devise theories.
Sequential	UNDERSTANDING	Global
Linear, orderly, learn in small incremental steps	⟷	Holistic, systems thinkers, learn in large leaps
Sequential learners are comfortable with mastering material presented in a logically ordered progression, learning it as the educator presents it. They follow linear reasoning processes when solving problems, and can work with material even when they only have a partial or superficial understanding of it. They may be strong in convergent thinking and analysis, and learn best when educators present material in a steady progression of complexity and difficulty.		Global learners tend to learn in bits and pieces: they may feel lost for days or weeks unable to solve simple problems or show the most rudimentary understanding, until suddenly they "get it" – the light bulb flashes and the entire puzzle finally comes together. And as a result, they may understand the material well enough to apply it to problems that leave most of the sequential learners baffled. Global learners may have difficulty working with material that they only have a partial or superficial understanding of. They tend to make intuitive leaps and then have difficulty explaining how they came up with solutions. They tend to do better at divergent thinking and synthesis and have the ability to move directly to more complex and difficult material.

features characterising inquiry-based learning as expressed by the National Research Council [11]:

- students create their own scientifically oriented questions;
- students give priority to evidence in responding to questions;
- students formulate explanations based on evidence;
- students connect explanations to scientific knowledge;
- students communicate and justify explanations.

IBL refers to a more student-centred perspective of learning Mathematics and Science that promotes a learning culture in which students are invited to work in ways similar to how mathematicians and scientists work. This means they have to observe phenomena, ask questions, and look for mathematical and scientific ways of how to answer these questions (carry out experiments, systematically control variables, draw diagrams, calculate, look for patterns and relationships, and make and prove conjectures). Students then go on to interpret and evaluate their solutions and effectively communicate their results through various means (discussions, posters, presentations, etc.). This also means that they should try to generalise the results obtained and the methods used, and connect them in order to progressively develop mathematical concepts and structures [8].

This definition embraces several different approaches to inquiry-based instruction, including [7]:

Structured inquiry—the teacher provides students with a hands-on problem to investigate, as well as the procedures, and materials, but does not inform them of expected outcomes. Students are to discover relationships between variables or otherwise generalize from data collected. These types of investigations are similar to those known as cookbook activities, although a cookbook activity generally includes more direction than a structured inquiry activity about what students are to observe and which data they are to collect.

Guided inquiry—the teacher provides only the materials and problem to investigate. Students devise their own procedure to solve the problem.

Open inquiry—this approach is similar to guided inquiry, with the addition that students also formulate their own problem to investigate. Open inquiry, in many ways, is analogous to doing science. Science fair activities are often examples of open inquiry.

Learning cycle—students are engaged in an activity that introduces a new concept. The teacher then provides the formal name for the concept. Students take ownership of the concept by applying it in a different context.

According to [10], activities in inquiry class could be as follows: Student led inquiry; Tackling unstructured problems; Learning concepts through IBL; Questioning that promotes reasoning; Students working collaboratively; Building on what students already know; Self and peer assessment.

T. Bell et al. [12] summarised the processes of inquiry based learning as follows:

- Orienting and asking questions: students make observations or gaze at scientific phenomena that catch their interest or arouse their curiosity. Ideally, they develop questions by themselves.
- Hypothesis generation is the formulation of relations between variables. Stating a hypothesis is a difficult task for many students.
- Planning in the narrower sense involves the design of an experiment to test the hypothesis and the selection of appropriate measuring instruments for deciding upon the validity of the hypothesis.
- Investigation as the link to natural phenomena is the empirical aspect of inquiry learning. It includes the use of tools to collect information and data, the implementation of experiments, and the organisation of the data pool.
- Analysis and interpretation of data form the basis of empirical claims and arguments for the proposition of a model.
- Model exploration and creation is a fundamental aspect of science learning. Models are used in science for several purposes. Students should learn to explore, create, test, revise, and use externalised scientific models that may express their own internalised mental models.
- In conclusion and evaluation activities, students extract the results from their inquiry. Conclusions might be drawn from data and in comparison with models, theories or other experiments.
- Communication represents the collaborative element of inquiry learning. Communication is a process that may span all other processes of scientific inquiry starting with the development of a research question and ending with the presentation or reporting of results.
- In a prediction, learners express their beliefs about the dynamics of a system, while in a hypothesis the relations of the variables are emphasised. This last category may also symbolise the unfinished inquiry process after reaching a conclusion where new questions and hypotheses arise from the research results.

An intervention model for a widespread dissemination and implementation of IBL is provided by mascil [10] design research project. It is aimed at promoting a widespread use of inquiry-based science teaching in primary and secondary schools. In addition, mascil connects Mathematics and Science education to the world of work: both inquiry-based science teaching and the connection to the world of work will make Mathematics and Science more meaningful to students. When doing inquiry-based tasks, students work like scientists and by doing so, they acquire competencies they need for their future professional and personal lives as active citizens [10].

The rest of the paper is organised as follows: methodology of the research is described in Section 2, research results are presented in Section 3, Discussion—in Section 4. The paper is concluded by Section 5.

2. Methodology of the research

As it was mentioned in Section 1.1, ontologies and recommender systems should be based first of all on established interconnections between students' learning styles and learning components (e.g., learning activities). While establishing those interconnections, high-quality learning styles models (e.g., FSLSM) and vocabularies of learning components (e.g., learning activities such as IBL) should be used, on the one hand, and experienced high-quality experts should participate in this work, on the other.

In order to interconnect FSLSM and IBL activities, a special questionnaire (see Table 3) was created by the authors for Lithuanian teachers experts in the area. These teachers are experienced in personalised learning, and they participated in numerous training activities and international projects in the area. The questionnaire was created in Lithuanian using FSLSM [6] and IBL activities and sub-activities vocabulary according to [12]. 9 IBL sub-activities (see Table 3) have been analysed by [12], and they have been included into the questionnaire.

The experts have been asked to fill in the questionnaire in terms of establishing suitability of proposed IBL activities and sub-activities [12] to students' learning styles according to FSLSM [6]. The level of suitability have been proposed to express in linguistic variables 'bad', 'poor', 'fair', 'good' and 'excellent'.

After teachers experts had filled in the questionnaire, the authors have mapped linguistic variables into non-fuzzy values using trapezoidal fuzzy numbers (TFNs) as presented below.

According to Ounaies et al. [13], the wide-used measurement criteria of the decision attributes quality are mainly qualitative and subjective. In this context, decisions are often expressed in the natural language, and evaluators are unable to assign exact numerical values to different criteria.

Assessment can be often performed by the linguistic variables such as 'bad', 'poor', 'fair', 'good' and 'excellent'. These linguistic variables allow reasoning with imprecise information, and they are commonly called fuzzy values. Integrating these different judgments to obtain a final evaluation is not evident. In order to solve this problem, [13] suggested using the fuzzy group decision making theory to obtain final assessment measures. According to their proposal, first, linguistic variable values should be mapped into fuzzy numbers, and, second, into non-fuzzy values. In this paper, the authors use trapezoidal fuzzy numbers (TFNs) for evaluating the level of suitability of IBL activities and sub-activities according to [12] to learning styles according to [6] (see Fig. 1).

$$\mu_M(x) = \begin{cases} 0, & \text{if} \quad x < a, \\ \frac{x-a}{b-a} & \text{if} \quad a \le x \le b, \\ 1, & \text{if} \quad b \le x \le c, \\ \frac{d-x}{d-c} & \text{if} \quad c \le x \le d, \\ 0, & \text{if} \quad x > d. \end{cases}$$

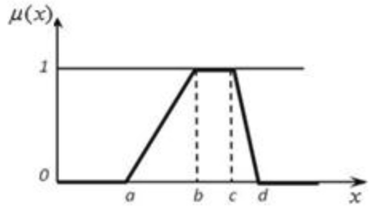

Fig. 1. Trapezoidal fuzzy numbers.

According to [14], in the case of using average TFNs, linguistic variables conversion into non-fuzzy values of the evaluation criteria should be as in Table 2.

Table 2. Conversion of linguistic variables and into non-fuzzy values

Linguistic variables	Trapezoidal non-fuzzy values
Excellent	1.000
Good	0.800
Fair	0.500
Poor	0.200
Bad	0.000

3. Research results

Thirteen teachers have filled in the questionnaire in September, 2015. This expert valuation was performed by mascil project's teachers-experts in Computer Engineering. The results are expressed in TFN ratings as presented in Table 3.

In Figure 2, Interconnections between IBL sub-

Table 3. Suitability of IBL activities and sub-activities to Felder-Silverman learning styles

IBL activity	IBL sub-activity	FSLSM learning style	Ratings
A1: Orienting and asking questions	A1.1. Observe phenomena	Active	0.86
		Reflective	0.59
	A1.2. Develop questions	Active	0.94
		Reflective	0.83
	A1.3. Respond to questions	Sensory	0.79
		Intuitive	0.62
A2: Hypothesis generation	A2.1. Select and complete hypotheses	Sequential	0.75
		Global	0.79
	A2.2. State hypothesis	Active	0.75
		Reflective	0.67
		Visual	0.85
		Verbal	0.82
A3: Planning	A3.1. Inquiry plan	Active	0.86
		Reflective	0.77
		Sensory	0.74
		Intuitive	0.75
	A3.2. Equipment and actions	Sensory	0.86
		Intuitive	0.77
		Visual	0.88
		Verbal	0.86
		Active	0.88
		Reflective	0.72
		Sequential	0.87
		Global	0.70
	A3.3. Supported planning	Sequential	0.91
		Global	0.85
A4: Investigation	A4.1. Explore	Sensory	0.78
		Intuitive	0.86
		Visual	0.81
		Verbal	0.73
		Active	0.89
		Reflective	0.90
		Sequential	0.87
		Global	0.71
	A4.2. Observe, conduct observation	Active	0.82
		Reflective	0.80
	A4.3. Experiment	Active	0.89
		Reflective	0.69
	A4.4. Organize data	Sequential	0.89
		Global	0.75
		Sensory	0.66
		Intuitive	0.70
A5: Analysis and interpretation	A5.1. Assess data	Sensory	0.78
		Intuitive	0.74
	A5.2. Interpret data	Sequential	0.78
		Global	0.78
		Visual	0.84
		Verbal	0.82
	A5.3. Synthesize new knowledge	Sequential	0.85
		Global	0.75
A6: Model exploration and creation	A6.1. Discover	Active	0.79
		Reflective	0.83
	A6.2. Develop	Active	0.84
		Reflective	0.79
	A6.3. Evaluate	Active	0.82
		Reflective	0.72
	A6.4. Expose	Visual	0.85
		Verbal	0.78
		Sensory	0.78
		Intuitive	0.71
		Active	0.79
		Reflective	0.69
A7: Conclusion and evaluation	A7.1. Generalize the results	Sequential	0.79
		Global	0.88
	A7.2. State conclusions	Active	0.87
		Reflective	0.82
	A7.3. Evaluate	Active	0.86
		Reflective	0.72
A8: Communication and justifying	A8.1. Discuss	Active	0.91
		Reflective	0.77
	A8.2. Share results	Active	0.92
		Reflective	0.70
	A8.3. Collaborate	Active	0.91
		Reflective	0.72
A9: Prediction	A9.1. Predict	Active	0.88
		Reflective	0.73
		Sequential	0.82
		Global	0.80
	A9.2.Formulate further questions	Active	0.88
		Reflective	0.78
A10: Discover relationships	A10.1. Explore	Sequential	0.78
		Global	0.76
	A10.2. Invest concepts	Sequential	0.82
		Global	0.78
	A10.3. Apply	Active	0.86
		Reflective	0.85

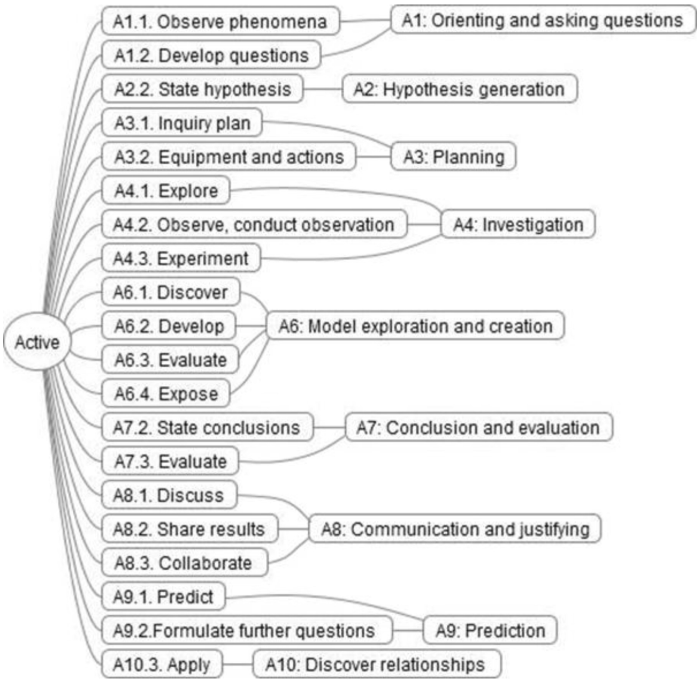

Fig. 2. Interconnections between IBL sub- activities and Felder-Silverman Active learning style.

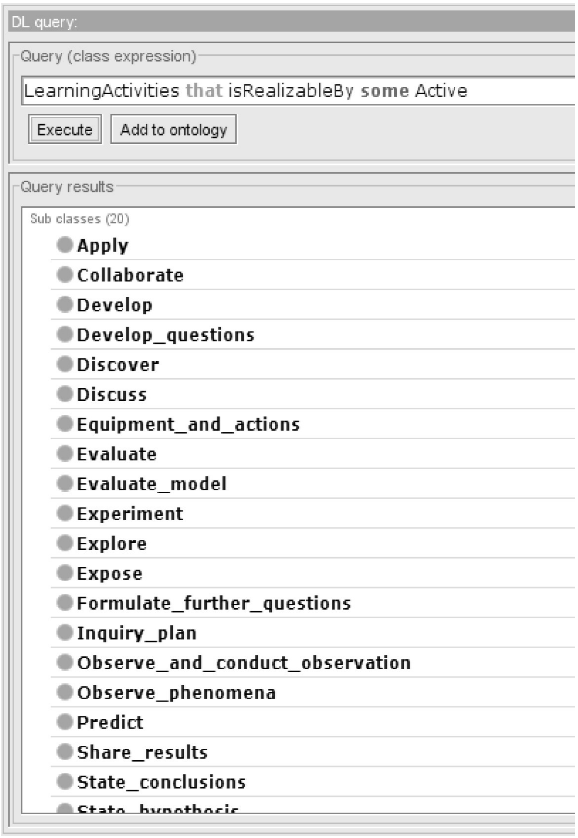

Fig. 3. Ontology example 1: Query for finding suitable IBL sub-activities by Felder-Silverman Active learning style.

activities and Felder-Silverman Active learning style are presented.

In Figures 3 and 4, some examples of created

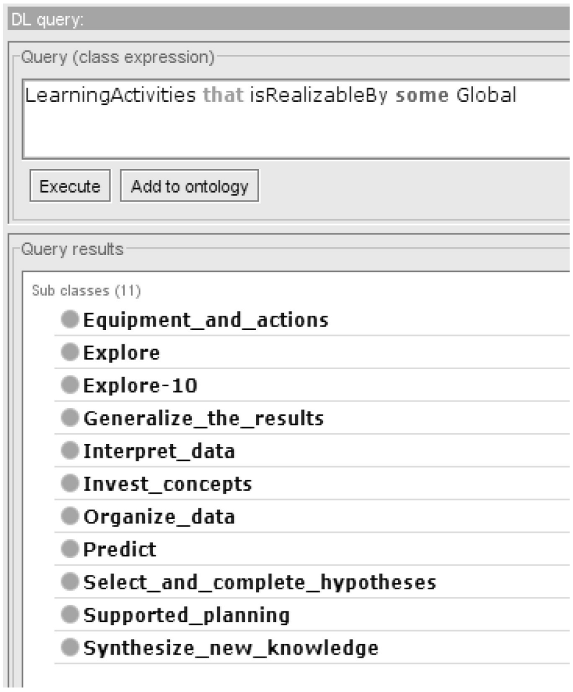

Fig. 4. Ontology example 2: Query for finding IBL sub-activities by Felder-Silverman Global learning style.

ontologies are presented for Active and Global learning styles.

4. Discussion

Based on interconnections presented in Table 3, ontologies to find suitable IBL sub-activities could be created for all 4 dimensions (by information type, sensory channel, information processing, and understanding) and 8 learning styles (sensory, intuitive; visual, verbal; active, reflective; sequential, global) according to FSLSM. Based on these ontologies, a recommender system could be created to propose suitable IBL activities and sub-activities to all students according to their learning styles.

This could significantly improve learning since the optimal student-centred research component is implemented. This also works in higher education sector, e.g. Zhou et al. study [15] investigated whether the inclusion of a student-centred research component in an introductory materials science course resulted in a larger knowledge gain relative to traditional pedagogies. Students in the redesigned class demonstrated higher knowledge gain relative to traditional lectures, consistent with previous studies that examined the effect of in-class active learning pedagogies. The post hoc survey showed a positive response of the students' with regards to improvements in their critical thinking, quality of learning, oral, written, and communication skills [15].

After that, suitable learning paths (scenarios) could be created for all students according to their personal needs using created recommender system. These learning paths (scenarios) should consist of the learning components (learning objects, activities, methods, tools, apps etc.) suitable to students' learning styles.

Future work should include creation of interconnections, ontologies, and recommender systems between FSLSM-based learners' profiles (models) and other learning components using research methodology presented in this paper.

The preferences of the components' suitability to learners' models could be expressed by TFN-based ratings as presented in Section 2 and Table 3.

5. Conclusion

The paper aims at establishing interconnections between Felder-Silverman learning styles model and inquiry-based learning activities and sub-activities. Interconnections are established using expert evaluation method based on trapezoidal Fuzzy numbers. Evaluation was performed by mascil project's teachers-experts in Computer Engineering. Based on created ontologies, a recommender system could be created to propose suitable IBL activities and sub-activities to all students according to their learning styles. The established interconnections and ontologies are useful while creating suitable IBL-based learning paths (scenarios) for students having different learning styles. These learning scenarios could be created using ontologies-based recommender systems for Computer Engineering education and STEM subjects with the help of created interconnections. The preferences of the learning components' suitability to learners' models could be expressed by TFN-based ratings as presented in the paper.

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