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Computational Thinking Skills and Adaptation Quality of Virtual Learning Environments for Learning Informatics*

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The paper aims to analyse and propose scientific methods suitable for evaluating the adaptation quality of Virtual Learning Environments (VLEs) matching Informatics learners' needs. The authors' approach consists of the consecutive application of the principles of multiple criteria decision analysis for identifying the VLEs adaptation quality criteria, sets portrait method to analyse the interconnections of the VLE adaptation quality criteria and the learners' computational thinking skills, fuzzy group decision making theory to obtain final evaluation measures of the VLEs quality criteria, and scalarization method to obtain the final results of evaluating the VLEs quality. While applying these methods, appropriate decision support system was developed. This system consists of the learners' computational thinking skills' questionnaires, observations results and conclusions, VLEs adaptation quality criteria, their ratings (values) and weights, and final evaluation results that propose a proper decision. This approach should help Universities and schools to create, buy, or find free VLE software mostly suitable for teaching and learning Informatics. Computational thinking term is detailed in the paper, and interconnected with the VLEs adaptation quality criteria using sets portrait method. After that, multiple criteria decision analysis approach is used to evaluate the adaptation quality of VLE in terms of its conformance with the learners' computational thinking styles. The experts' additive utility function is proposed to use for the expert evaluation of the adaptation quality of VLEs. Trapezoidal fuzzy numbers method is proposed to use for establishing both weights and ratings (values) of the VLEs quality criteria matching learners' computational thinking styles. Practical example of the experimental evaluation of three popular open source VLEs is also presented in the paper. Presented research results are particularly useful for Informatics/software engineering education.

Keywords: engineering education; decision support system; virtual learning environments; computational thinking; multiple criteria decision analysis; expert evaluation; quality; adaptation; trapezoidal fuzzy numbers

1. Introduction

Different learning platforms are widely used in educational institutions to teach and learn different disciplines. We can separate the two types of these platforms used for teaching and learning Informatics (Computer Science):

1. Specialised learning platforms used for teaching/learning programming (e.g. TRAKLA2, ViLLE, Greenfoot, etc.).
2. Common purpose Virtual Learning Environments (VLEs, also known as Learning Management Systems) used mainly for loading Informatics courses and tasks. VLEs are often used to interconnect with the specialised compilers or the other specific programming tools.

While planning to use any VLE to teach/learn Informatics, the main question is about the quality of this kind of the learning software and its suitability for Informatics learners.

Computational thinking (CT) is broadly defined as the ability to abstract problems and formulate solutions that can be automated. CT revolves around abstraction and automation, indicating the ability to dissect problems, abstract the high-level rules, and use technology to automate the problem solving process. While abstraction implies the process of selecting information worthy of attention, automation is the use of tools or technology to amplify the power of abstraction [1]. According to [1], CT also involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to Informatics. In an increasingly information-based society, CT is viewed as becoming an essential skill, the main skill necessary for learning Informatics. Therefore, in the paper, VLEs quality criteria are interconnected with the learners' CT skills using sets portrait method.

The aim of the paper is to analyse and propose suitable scientific methods for the expert evaluation of the quality of VLEs and their suitability to particular learners' CT styles. For this purpose, VLEs adaptation quality criteria are analysed in more detail, because these particular criteria deal with CT skills mostly. Practical example of the experimental evaluation of three popular open

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source VLEs is also presented in the paper. Presented approach should help Universities and schools to create, buy, or find free VLE software mostly suitable for teaching and learning Informatics.

While performing the research, the appropriate decision support system was developed. This system consists of the learners' computational thinking skills questionnaires, observation results and conclusions, VLEs quality criteria, their ratings (values) and weights, and final evaluation results that propose a proper decision.

2. Research methodology

While developing learning environments for software engineering disciplines, the decisive role is dedicated to the means for the design of the software programs of complex structure, as well as the means of their support and reengineering. They should be capable of illustrating the requirements of all the software development stages, from building formal specifications to the preparation of documentation.

Description of the features of programming languages shows that the absolute majority of them are dedicated to the object-oriented programming technology. Only C++ and Object Pascal languages, that are rapidly losing their popularity in software engineering, still use hybrid technology combining procedural and object-oriented paradigms.

In introductory stage, disciplines are concentrated at the description of simple data structures and typical control algorithms using procedural programming tools. Relevant practical programming issues are addressed only in later stages, using the applied software packages and Java or dotNet technologies. Following this approach, choice of an ordinary relevant compiler is sufficient for initial studies, while studies of software engineering and other special disciplines require the development of specific individual learning environments [2]. Therefore, we can successfully use the general purpose software packages such as VLEs in introductory course.

Expert evaluation is referred here as multiple criteria evaluation of the learning software aimed at selection of the best alternative based on score-ranking results [3]. VLEs should be evaluated against a number of the quality criteria. These criteria are often conflicting. Some VLEs could be of excellent quality against the particular criteria, and poor—against the other ones, and vice versa. Therefore, expert evaluation of the VLEs quality is a typical case where Multiple Criteria Decision Analysis (MCDA) methods should be applied.

MCDA is a group of problem solving methods to find consensus and compromises between conflicting goals (i.e. multiple criteria) in complex problems.

In real life, problems might be complex and confusing and they typically involve a wide range of criteria that need to be considered. They might involve conflicting criteria, and the conflicts between different stakeholders about the importance of the criteria in making the decision. It might even require defining the criteria as they are not clear at the initial stage of the problem [3].

The general goal of MCDA is to assist individual or groups of decision makers to choose the best alternative. MCDA is defined as a collection of formal approaches which seek to take into account the multiple criteria in order to help decision makers to explore different decision alternatives [4].

According to [5], despite the widespread use of e-learning systems and the considerable investment in purchasing or developing them, there is no consensus on a standard framework for evaluating the system quality.

Quoting [6], "there is a wide range of multiple criteria decision making problem solution techniques, varying in complexity and possible solutions. Each method has its own strength, weaknesses and possibilities to be applied".

In the paper, the authors' approach is to use the multiple criteria evaluation method expressed by the experts' additive utility function (1) presented below. This function includes the weights and the ratings (values) of the quality criteria of the VLEs alternatives. This method was presented for the first time in [3], and refined in [7].

According to this method, in order to evaluate VLEs, we should use three consecutive stages: (a) to identify VLEs quality criteria (i.e. create the VLE quality model), (b) to identify a suitable method for the expert evaluation of the quality of VLEs alternatives expressed by formula (1) below, and (c) to apply this method by calculating the evaluating results of formula (1) by adding all the numerical ratings (values) multiplied by the weights of the quality criteria.

This method is well-known in the theory of optimisation methods and is named "scalarization method", and is represented by the experts' additive utility function (1). A possible decision here could be to transform multiple criteria task into one-criterion task obtained by adding all the ratings (values) of the criteria multiplied by their weights. It is valid from the point of view of the optimisation theory, and a special theorem exists for this case.

$$f(X) = \sum_{i=1}^{m} a_i f_i(X) \qquad (1)$$

Here $f_i(X)$ is the rating (i.e. non-fuzzy value) of the criterion i for the each of the examined VLEs alternatives X.

The weights here should be "normalised" according to the "normalisation" requirement:

$$\sum_{i=1}^{m} a_i = 1, a_i > 0 \qquad (2)$$

The aim of the paper is to analyse methods for the expert evaluation of the quality of VLEs and their suitability to the learners' computational thinking styles. Methods for analysing the quality of VLEs matching personal learners' skills were proposed by the authors in [3, 7]. Generally, learning personalisation issues are broadly discussed in scientific literature [8–11].

Computational thinking is a term coined in [1] to describe a set of thinking skills, habits, and approaches that are integral to solving complex problems using a computer and widely applicable in the information society [12]. Thinking computationally draws on the concepts that are fundamental to Informatics, and involves systematically and efficiently processing information and tasks.

According to [12], CT involves defining, understanding, and solving problems, reasoning at multiple levels of abstraction, understanding and applying automation, and analysing the appropriateness of the abstractions made. CT shares elements with various other types of thinking (e.g. algorithmic thinking, engineering thinking, design thinking, and mathematical thinking). In [12], CT has been described as the use of abstraction, automation and analysis in problem solving. Abstraction, automation, and analysis skills will be analysed further in Section 3, and will be interconnected with VLEs adaptation quality criteria presented below in Section 4.1.

3. Related work: Computational thinking and VLE adaptation quality

Students from a range of backgrounds are able to abstraction, automation, and analysis to create original products when given access to rich learning environments that include skilled teachers, developmental considerations, and usually include new technology [12].

According to [12], *abstraction* is "the process of generalizing from specific instances". In problem solving, abstraction may take the form of stripping down a problem to what is believed to be its bare essentials. Abstraction is also commonly defined as the capturing of the common characteristics or actions into one set that can be used to represent all other instances. *Automation* is a labour saving process in which a computer is instructed to execute a set of repetitive tasks quickly and efficiently compared to the processing power of a human. In this light, computer programs are "automations of abstractions". *Analysis* is a reflective practice that refers to the validation of whether the abstractions made were correct [12].

The Computer Science Teacher Association emphasized the role of CT in K-12 classrooms as "a problem solving methodology that can be automated and transferred and applied across subjects" [13].

In order to investigate the learners' CT skills, appropriate learners' questionnaires and/or observations should be performed, and their results and conclusions should be handled in the appropriate decision support system.

Now let us try to interconnect (i.e. to portrait the sets of) abstraction, automation, and analysis with the VLEs adaptation quality criteria. This interconnection should show us which particular CT skills interconnect with particular VLEs adaptation quality criteria.

Besides that, the CT skills and VLEs adaptation quality criteria sets portrait analysis should show us the weights of the VLEs quality criteria in terms of the level of their correspondence with the particular CT skills.

There are some previous works where different sets of VLEs quality criteria have been analysed. In [14], the methodology presented in [15] was analysed to identify the VLEs technological quality criteria, and the framework presented in [16] was analysed to identify pedagogical and organisational criteria of the VLEs quality.

In [17], evaluation of open source e-learning platforms (i.e. VLEs) where the main focus is on adaptation issues was presented in more detail. An e-learning course should not be designed in a vacuum; rather, it should match students' needs and desires as closely as possible, and adapt during course progression [17].

In the authors' previous papers [3, 7], a comprehensive model of the VLEs technological quality criteria was developed combining both general technological quality criteria developed in [15], and adaptation quality criteria developed in [17].

According to [17], VLEs adaptation quality criteria are adaptability, personalisation, extensibility, and adaptivity capabilities of the platforms.

VLE adaptation criteria developed in [17] are relevant to the aim of the paper, because they deal with the learners' computational thinking skills mostly.

In the paper, we'll not analyse general technological quality criteria such as Overall architecture and implementation, Interoperability, Internationalisation and localisation, and Accessibility [14, 15] since these criteria do not directly interconnect with the learners' CT skills.

4. Multiple criteria evaluation of the quality of VLE matching learners' computational thinking skills

4.1 Sets portrait of computational thinking skills and VLE adaptation quality criteria

There is a clear interconnection between CT skills and VLE adaptation quality criteria. One of the effective methods to analyse if there are any interconnections between two sets is so-called Sets Portrait method. Let us use this method to analyse interconnections between CT skills and VLE adaptation quality criteria.

Let us examine CT skills—abstraction, automation, and analysis— presented in [12], and VLE adaptation quality criteria presented in [17].

According to [17], the VLE adaptation criteria are as follows:

1. *Adaptability*: it includes all facilities to customise the VLE to suit the educational institution needs (e.g. the language or design).
2. *Personalisation* aspects: they indicate the facilities of each individual user to customise his/her own view of the VLE.
3. *Extensibility*: in principle, it is possible for all open source products. Nevertheless, there can be great differences, e.g. a good programming style or the availability of a documented application programming interfaces could be helpful.
4. *Adaptivity*: it indicates all kinds of the automatic adaptation to the individual user's needs (e.g. personal annotations of learning objects or automatically adapted content).

In order to establish the proper weights of the VLE adaptation quality criteria, let us use Qualitative Weight and Sum approach (QWS) presented in [17].

QWS establishes and weights a list of criteria and is based on the use of symbols. There are six qualitative levels of importance for the weights, frequently symbols are used: (1) E = Essential; (2) * = Extremely valuable; (3) # = Very valuable; (4) + = Valuable; (5) | = Marginally valuable; and (6) 0 = Not valuable. In [17], the weight of a criterion determines the range of values that can be used to measure a product's performance. For a criterion weighted #, for example, the product can only be judged #, +, |, or 0, but not *. This means that lower-weighted criteria cannot overpower higher-weighted criteria. To evaluate the results, the different symbols given to each product are counted. Example results can be 2*, 3#, 3| or 1*, 6#, 1+. The product can now be ranked according to these numbers. But the results are sometimes not clear. There is no doubt that 3*, 4#, 2| is better than 2*, 4#, 2| but it is not clear whether it is better than 2*, 6#, 1+. In the latter case further analysis has to be conducted.

Table 1. CT skills and VLE adaptation quality criteria sets portrait using QWS approach

	Abstraction	Automation	Analysis
Adaptability	+	+	+
Personalisation	*	*	*
Extensibility	+	+	+
Adaptivity	*	*	*

Indeed, Personalisation (i.e. facilities of each individual user to customise his/her own view of the VLE), and Adaptivity (i.e. all kinds of the automatic adaptation to the individual user's needs) have direct extremely important impact on personalising one's learning in VLE. In such kind of VLE, learners can customise some VLE features to match his/her learning style incl. his/her personal CT style. Besides that, VLE could automatically adapt its own features incl. content and communication/collaboration plug-ins to match the requirements of the particular learning style. Therefore, these criteria are extremely valuable for particular learners' CT styles.

On the other hand, VLE adaptability to suit the educational institution needs, and its extensibility have only indirect impact on learning personalisation possibilities. Indeed, Adaptability includes all facilities to customise the VLE to suit the whole educational institution needs (e.g. the language or design), but not the particular learner needs. VLE Extensibility features such as a good programming style or the availability of a documented application programming interfaces also do not have direct impact on the particular learner's possibilities to use his/her customised learning path in VLE. Therefore, these adaptation criteria are valuable features for particular learners' CT styles, but not extremely.

4.2 Trapezoidal fuzzy numbers

In order to evaluate the adaptation quality of VLE (i.e. VLE's suitability to particular learners' CT styles), we need to use function (1) presented in Section 2.

Now let us focus on one of the methods called Trapezoidal Fuzzy Numbers (TzFNs) method suitable to establish the numerical weights and ratings (values) of the VLE adaptation quality criteria. There is scientific evidence that this method is convenient for evaluating the quality of many different VLEs alternatives in the market. This method for evaluating the quality of VLEs was used for the first time in [18] and applied in the further research presented in [3].

According to [19], 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". Several methods such as QWS approach presented in [17] apply the symbols E, *, #, +, |, and 0 to express the values of the evaluated quality. These linguistic variables and symbols 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, [19] suggest using the fuzzy group decision making theory to obtain final assessment measures.

According to [20], TzFNs are a class of the fuzzy set representation. A TFzN is expressed by four real numbers (Fig. 1). TzFNs membership functions are as follows:

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

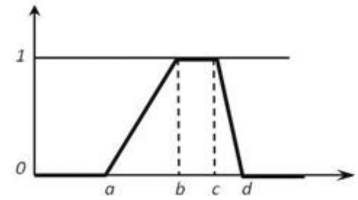

Fig. 1. Trapezoidal fuzzy numbers (according to [20]).

Conversion of these qualitative values into TzFNs (non-fuzzy values) is as follows (according to [19]):

Excellent	(0.800, 1.000, 1.000, 1.000)
Good	(0.600, 0.800, 0.800, 1.000)
Fair	(0.300, 0.500, 0.500, 0.700)
Poor	(0.000, 0.200, 0.200, 0.400)
Bad	(0.000, 0.000, 0.000, 0.200)

Therefore, in the case of using the average TzFNs, linguistic variables conversion into triangular non-fuzzy ratings (values) and weights of the evaluation criteria should be as follows:

Excellent/extremely valuable, essential	1.000
Good/very valuable	0.800
Fair/valuable	0.500
Poor/marginally valuable	0.200
Bad/not valuable	0.000

Now let us use these trapezoidal non-fuzzy values to establish the ratings of the VLEs adaptation quality criteria presented in Section 4.1.

4.3 Ratings of the VLE quality criteria

In [17], the QWS approach was adapted in a way where the essential criteria are assessed in a pre-evaluation phase. These minimum criteria cover three general usage requirements: an active community, a stable development status, and a good documentation of the platform. The fourth criterion incorporated the didactical objective and means that the platform's focus is on the presentation of content instead of communication functionalities.

At the beginning of the evaluation, 36 platforms were chosen and evaluated according to the minimum criteria have been selected in [17]. Nine platforms (ATutor 1.4.11, Dokeos 1.5.5, dotLRN 2.0.3, based on OpenACS 5.1.0, Ilias 3.2.4, LON–CAPA 1.1.3, Moodle 1.4.1, OpenUSS 1.4 extended with Freestyle Learning 3.2, Sakai 1.0, and Spaghettilearning 1.1) meet the criteria. Next, these nine platforms were tested in detail. A questionnaire and an example of a real life teaching situation, covering instructions for creating courses, managing users and simulating course activities, were designed and applied to each platform. Finally, eight categories established in [17]: communication tools, learning objects, management of user data, usability, adaptation, technical aspects, administration, and course management.

The evaluation results of the adaptation category of the three most popular open source VLEs are presented in Table 2.

These results were obtained in the research presented in [3, 7]. These results are based on the VLEs adaptation quality evaluation results [17] using conversion of QWS symbols into trapezoidal non-fuzzy values presented in Section 4.2.

Examining the results from a vertical perspective, it can be seen that the adaptability and the personalisation subcategories yield a broad range of results. The majority of the platforms were estimated as very good with regard to extensibility. In contrast, adaptivity features are underdeveloped.

Table 2. VLEs adaptation criteria ratings (according to [7])

	ATutor	Ilias	Moodle
Adaptability	0.200	0.500	0.800
Personalisation	0.800	0.800	0.500
Extensibility	0.800	1.000	1.000
Adaptivity	0.200	0.000	0.200

4.4 Weights of the VLE quality criteria and practical example of evaluating VLEs

The aforementioned multiple criteria evaluation method of the VLEs quality used by the authors is represented by the experts' additive utility function (1) including the VLEs quality criteria's ratings (values) and weights.

Let us use TzFNs method also for establishing the proper weights of the quality criteria.

If an expert evaluator establishes a weight of the criteria i in a form of a linguistic variable, we can convert it into the triangular fuzzy number m_f^i.

According to [21], if we have t experts we can calculate it using the experts' average (3):

$$m_f^i = \frac{1}{t}\sum_{k=1}^{t} m_k^i \tag{3}$$

If we want to normalise the weights of the quality criteria, we should apply formula (4):

$$a_i = \frac{m_f^i}{\sum_{s=1}^{m} m_f^s} \tag{4}$$

In our case, we have two experts-evaluators, i.e. the authors of the paper.

Now we have all the necessary data (i.e. the TzFNs ratings and weights of the criteria) to perform practical evaluation of the VLEs adaptation quality matching the particular learners' CT styles.

The results of this evaluation of the VLEs adaptation quality for the general case (i.e. when the experts do not evaluate suitability of the VLE to particular learners' CT styles), and for the particular case (i.e. when the experts are interested in evaluating suitability of the VLE to particular learners' styles), are as follows:

In the general case (where all the weights are equal), according to the normalisation requirement (2), all a_i = 0.250.

In this case, the final results of evaluating the adaptation quality of VLEs (presented in Table 2) applying the weights calculated using formulas (3) and (4) are as follows:

$$f(X) = \sum_{i=1}^{m} a_i f_i(X) = (\,0.5000 \quad 0.5750 \quad 0.625\,0) \tag{5}$$

The results in matrix (5) mean that Moodle meets 62.50% quality in comparison with the ideal (between "fair" and "good)", Ilias—57.50% (more than "fair"), and ATutor—50.00% ("fair").

According to this experimental evaluation results, Moodle is the best alternative (among the evaluated) from adaptation point of view in the general case.

Moodle can be seen as the best VLE concerning adaptation issues also according to [17]. Moodle provides an adaptive feature called "lesson" where learners can be routed automatically through pages depending on the answer to a question after each page. Furthermore, the extensibility is supported very well by a documented API, detailed guidelines, and templates for programming. Also adaptability and personalisation aspects are included in Moodle. Templates for themes are available and can be selected by the administrator. Students can choose out of more than 40 languages.

In the particular case (when we analyse VLE suitability to particular learners' CT styles, i.e. abstraction, automation and analysis), in conformity with Table 1 and the VLEs quality criteria weights' formulas (3)–(4), we'll obtain the following weights of the VLE quality criteria: $a_{1,3}$ = 0.1667, and $a_{2,4}$ = 0.3333.

Using these weights and the ratings (values) of the VLE adaptation quality criteria presented in Table 2, as well as the experts' additive utility function (1), we can obtain the final results of evaluating the VLEs adaptation quality matching the learners' CT styles as follows:

$$f(X) = \sum_{i=1}^{m} a_i f_i(X) = (\,0.5000 \quad 0.5167 \quad 0.5335\,) \tag{6}$$

The results in matrix (6) mean that Moodle meets 53.35% quality in comparison with the ideal, Ilias—51.67%, and ATutor—50.00%.

According to these experimental evaluation results, Moodle is also the best alternative (among the evaluated) from adaptation point of view in the case of conformance with the particular learners' CT styles.

5. Discussion

According to Table 1, personalisation aspects and automatic adaptivity are the main VLE features matching with the learners' computational thinking skills mostly. Therefore, the main future research trends should involve improvement of both personalisation aspects and automatic adaptivity features of VLEs matching particular learners' styles.

Several works in the area are already performed in Europe, e.g. research on Intelligent Adaptive Learning Environment (IALE) presented in [22], Adaptive Learning Environments (ALE) presented in [23], research on adaptivity features to a regular LMS to support creation of advanced eLessons presented in [24], and research on diagnosing students' learning style in an educational hypermedia system presented in [25].

There is a lack of the research on using so-called Semantic Web (or Web 3.0) for intelligent semantic search of the content suitable for the particular learning styles, incl. CT skills. If there should exist the qualitative technologies for semantic intelligent search of the relevant learning content on the Web, the learners should get the additional possibility to use this suitable content in their VLEs.

On the other hand, there is a lack of the research on personal learning environments suitable for different learning styles.

Therefore, research on future Semantic Web and personal learning environments should be the core research trends to improve personalisation aspects and automatic adaptivity of VLEs.

6. Conclusions

The research results presented in the paper show that the complex consecutive application of the authors' approach is: (a) usable in real life situations when Universities and schools should decide on purchase of VLEs mostly suitable for teaching and learning Informatics, and (b) could significantly improve CT skills of learners while applying VLEs characterised by high personalisation and adaptivity level.

The authors' approach consists of the consecutive application of (1) the principles of multiple criteria decision analysis for identifying the VLEs quality criteria, (2) sets portrait method to analyse the interconnections of the VLE adaptation quality criteria and the learners' computational thinking skills (i.e. abstraction, automation, and analysis), (3) fuzzy group decision making theory (i.e. TzFNs) to obtain final evaluation measures both for the weights and ratings (values) of the VLEs quality criteria, and (4) scalarization method to obtain the final results of evaluation of the VLEs quality.

As the results of the research, the appropriate decision support system was developed. This system consists of the learners' computational thinking skills questionnaires, observation results and conclusions, VLEs quality criteria, their ratings (values) and weights.

According to the results obtained, VLE Moodle is the best alternative among the evaluated popular open source VLEs both from general point of view, and from the point of view of the VLE features' conformance with the particular learners' CT styles.

VLEs experimental evaluation results show that the proposed scientific approach is quite objective, exact, and simply to use for selecting the qualitative VLEs alternatives in the market to match the particular learners' CT styles.

Presented research results are particularly useful for Informatics/software engineering education.

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