Methodology for Evaluating Quality and Reusability of Learning Objects

Eugenijus Kurilovas[1,2], Virginija Bireniene[2,3] and Silvija Serikoviene[1,2]
[1]Vilnius University Institute of Mathematics and Informatics, Vilnius, Lithuania
[2]Centre of Information Technologies in Education, Vilnius, Lithuania
[3]Klaipeda Simon Dach Basic School, Lithuania
Eugenijus.Kurilovas@itc.smm.lt
miride@gmail.com
silvija.serikoviene@gmail.com

Abstract: The aim of the paper is to present the scientific model and several methods for the expert evaluation of quality of learning objects (LOs) paying especial attention to LOs reusability level. The activities of eQNet Quality Network for a European Learning Resource Exchange (LRE) aimed to improve reusability of LOs of European Schoolnet's LRE service for schools are analysed in more detail. As a pan-European service, the LRE particularly seeks to identify LOs that can "travel well" (i.e., reusable) across national borders and can be used in a cultural and linguistic context different from the one in which they were created. The primary aim is to improve the quality of LOs in LRE. eQNet is doing this by establishing a network consisting of researchers, policy makers, and practitioners (teachers) that develops and applies "travel well" quality criteria to both existing LRE content as well as that to be selected in future from national repositories. The vision driving the LRE is that a significant percentage of high quality LOs developed in different countries, in different languages and to meet the needs of different curricula can be re-used at European level. The main problem of all existing approaches in the area is a high level of the expert evaluation subjectivity. The authors analyse several scientific approaches, theories, methods and principles to minimise the subjectivity level in expert evaluation of LOs quality, namely: (1) multiple criteria decision analysis approaches for identification of quality criteria, (2) technological quality criteria classification principle, (c) fuzzy group decision making theory to obtain evaluation measures, (d) normalisation requirement for criteria weights, (e) scalarisation method and (f) trapezoidal fuzzy method for LOs quality optimisation. The authors show that the complex application of these approaches could significantly improve the quality of expert evaluation of LOs and noticeably reduce the expert evaluation subjectivity level. The paper also presents several examples of practical application of these approaches for LOs quality evaluation for Physics and Mathematics subjects.

Keywords: learning objects, multiple criteria decision analysis, quality evaluation, reusability, optimisation

1. Introduction: Evaluation of learning objects in eQNet project

The aim of the paper is to present the scientific model and several methods for the expert evaluation of quality of learning objects (LOs) paying especial attention to their reusability level. This is also one of the main objectives of a new eQNet (eQNet 2011) project.

eQNet is a three-year (September 2009-2012) Comenius Multilateral Network funded under the European Commission's Lifelong Learning programme. The project is coordinated by European Schoolnet (EUN) and involves 9 Ministries of Education or agencies nominated to act of their behalf. The primary aim is to improve the quality of learning objects (LOs) in European Schoolnet's Learning Resource Exchange – LRE (LRE 2011) which currently offers almost 130,000 LOs and assets from over 25 providers. As a pan-European service, the LRE particularly seeks to identify LOs that "travel well" (i.e., reusable) across national borders and can be used in a cultural and linguistic context different from the one in which they were created (eQNet 2011).

eQNet is doing this by establishing a network consisting of researchers, policy makers and practitioners (teachers) that develops and applies "travel well" quality criteria to both existing LRE content as well as that to be selected in future from national repositories. The vision driving the LRE is that a significant percentage of high quality LOs developed in different countries, in different languages and to meet the needs of different curricula can be re-used at European level. eQNet provides a forum for joint reflection and co-operation related to the exchange and re-use of educational content and allows network members to:

- Better share information and expertise particularly related to "travel well" quality criteria (i.e., pedagogical, technical and intellectual property rights (IPR) factors);
- Develop new frameworks to improve the quality of LOs and metadata in both national repositories and the LRE, including the growing volume of user-generated content and metadata, as well as to

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improve the multilinguality of LRE content as a result of the translation of metadata, making use, where appropriate, of automatic metadata translation approaches and technologies;

- Enable schools to participate in a Community of Practice related to the use LOs at European level.

Major results will include:

- The development of “travel well” quality criteria to more easily identify LOs with the potential for cross-border use (this work package is coordinated by the Lithuanian partner, in particular by the author of the paper);
- The practical application by teachers of these criteria to >3,500 LOs in the LRE;
- ‘Showcases’ of the best of these LOs in a “travel well” section of the LRE portal;
- Where necessary, the enrichment of selected LOs with new or better metadata;
- A Community of Practice for teachers around these LOs (eQNet 2011).

2. Methodology of the research

One of the main features achieving the high LOs effectiveness and efficiency level is LOs reusability. The need for reusability of LOs has at least three elements (McCormick *et. al.* 2004, Kurilovas 2009):

(1) Interoperability: LO is interoperable and can be used in different platforms.

(2) Flexibility in terms of pedagogic situations: LO can fit into a variety of pedagogic situations.

(3) Modifiability to suit a particular teacher’s or student’s needs: LO can be made more appropriate to a pedagogic situation by modifying it to suit a particular teacher’s or student’s needs.

Reusability of LOs (or their ability to “travel well” between different contexts and education systems) is considered by the authors as a part of the overall quality of LOs. This means that any high quality LO has some reusability level (or potential to “travel well”), but this does not mean that any reusable LO is quality one.

The main problem analysed in the paper is how to establish

(1) a ‘proper’ set of LOs “travel well” quality evaluation criteria that should reflect the objective scientific principles of construction a *model* (criteria tree) for LOs “travel well” quality evaluation, and

(2) ‘proper’ *methods* for evaluation of LOs “travel well” quality.

According to (Oliver 2000), *evaluation* can be characterised as “the process by which people make judgements about value and worth”. In the context of learning technology this judgement process is complex and often controversial. Although the notion of evaluation is rooted in a relatively simple concept, the process of judging the value of learning technology is complex and challenging. *Quality evaluation* is defined as “the systematic examination of the extent to which an entity (part, product, service or organisation) is capable of meeting specified requirements” (ISO/IEC 1999). *Expert evaluation* is referred here as the multiple criteria evaluation of LOs aimed at selection of the best alternatives (i.e., LOs) based on score-ranking results (Kurilovas and Dagiene 2009a).

According to (Zavadskas and Turskis 2010), there is a wide range of multiple criteria decision making (MCDM) problem solution techniques, varying in complexity and possible solutions. Each method has its own strength, weaknesses and possibilities to be applied. But, according to (Zavadskas and Turskis 2010), there are still no rules determining the application of multi-criteria evaluation methods and interpretation of the results obtained.

If the set of decision alternatives (LOs) is assumed to be predefined, fixed and finite, then the decision problem is to choose the optimal alternative or, maybe, to rank them. But usually the experts have to deal with the problem of optimal decision in the multiple criteria situation where the objectives are often conflicting. In this case, an optimal decision is the one that maximises the expert’s utility.

These principles of identification of quality evaluation criteria have been analysed in multiple criteria decision analysis (MCDA) theory related research works (e.g., (Belton and Stewart 2002)).

Evaluation of LOs quality is a typical case where the criteria are conflicting, i.e., LOs could be very qualitative against several criteria, and not qualitative against the other ones, and vice versa. Therefore, the authors propose to use MCDA approach for creation of LOs quality evaluation *model*.

LOs multiple criteria evaluation *method* used by the authors in eQNet is referred here as the experts' additive utility function represented by formula (1) below including LOs evaluation criteria, their ratings (values) and weights (Kurilovas and Serikoviene 2010).

This method is well-known in the theory of optimisation methods and is named "*scalarisation method*". A possible decision here could be to transform multi-criteria task into one-criterion task obtained by adding all criteria together with their weights. It is valid from the point of view of the optimisation theory, and a special theorem exists for this case (Kurilovas and Serikoviene 2010).

Therefore, here we have the experts' additive utility function:

$$f(X) = \sum_{i=1}^{m} a_i f_i(X), \sum_{i=}^{m} a_i = , a_i >). \tag{1}$$

where f_i (X_j) is the rating (i.e., non-fuzzy value) of the criterion i for the each of the examined LOs alternatives X_j. The weights here should be 'normalised' according to the *'normalisation' requirement*

$$\sum_{i=}^{m} a_i = , a_i >). \tag{2}$$

According to (Zavadskas and Turskis 2010), the normalisation aims at obtaining comparable scales of criteria values. The major is the meaning of the utility function (1) the better LOs meet the quality requirements in comparison with the ideal (i.e., 100%) quality.

3. Literature analysis and research results

This section is aimed to apply the aforementioned scientific approaches in order:

(1) to propose a suitable scientific model for evaluation of quality of LOs,

(2) to propose suitable scientific methods for evaluation of quality of LOs, and

(3) to present the experimental evaluation results using the proposed evaluation model and methods.

3.1 Learning objects quality evaluation model

The following *principles of identification of quality evaluation criteria* are relevant to all MCDA approaches (Belton and Stewart 2002):

(1) Value relevance: Are the decision makers able to link the concept to their goals, thereby enabling them to specify preferences which relate directly to the concept?

(2) Understandability: It is important that decision makers have a shared understanding of concepts to be used in an analysis.

(3) Measurability: All MCDA implies some degree of measurement of the performance of alternatives against specified criteria, thus it must be possible to specify this in a consistent manner. It is usual to decompose criteria to a level of detail which allows this.

(4) Non-redundancy: Is there more than one criterion measuring the same factor? When eliciting ideas often the same concept may arise under different headings. One can easily check for criteria

which appear to be measuring the same thing by calculating a correlation coefficient if appropriate data is available, or carrying out a process of matching as associated with analysis of repertory grids.

(5) Judgmental independence: Criteria are not judgementally independent if preferences with respect to a single criterion, or trade-offs between two criteria, depend on the level of another.

(6) Balancing completeness and conciseness: a number of authors note that desirable characteristics of a value tree are that it is complete, i.e., that all important aspects of the problem are captured, and also that it is concise, keeping the level of detail to the minimum required.

(7) Operationality: The model is usable with reasonable effort – that the information required does not place excessive demands on the decision makers. The context in which the model is being used is clearly important in judging the usability of a model.

(8) Simplicity versus complexity: The value tree, or criteria set is itself a simple representation, capturing the essence of a problem, which has been extracted from a complex problem description. The modeller should strive for the simplest tree which adequately captures the problem for the decision maker.

LOs quality evaluation model based on these MCDA criteria identification principles is presented in the Fig. 1. This model consists of eight quality criteria, four of them dealing with technological quality, three – with pedagogical quality of LOs, and one – with IPR issues. This model includes three groups of criteria, namely, technological, pedagogical and IPR criteria.

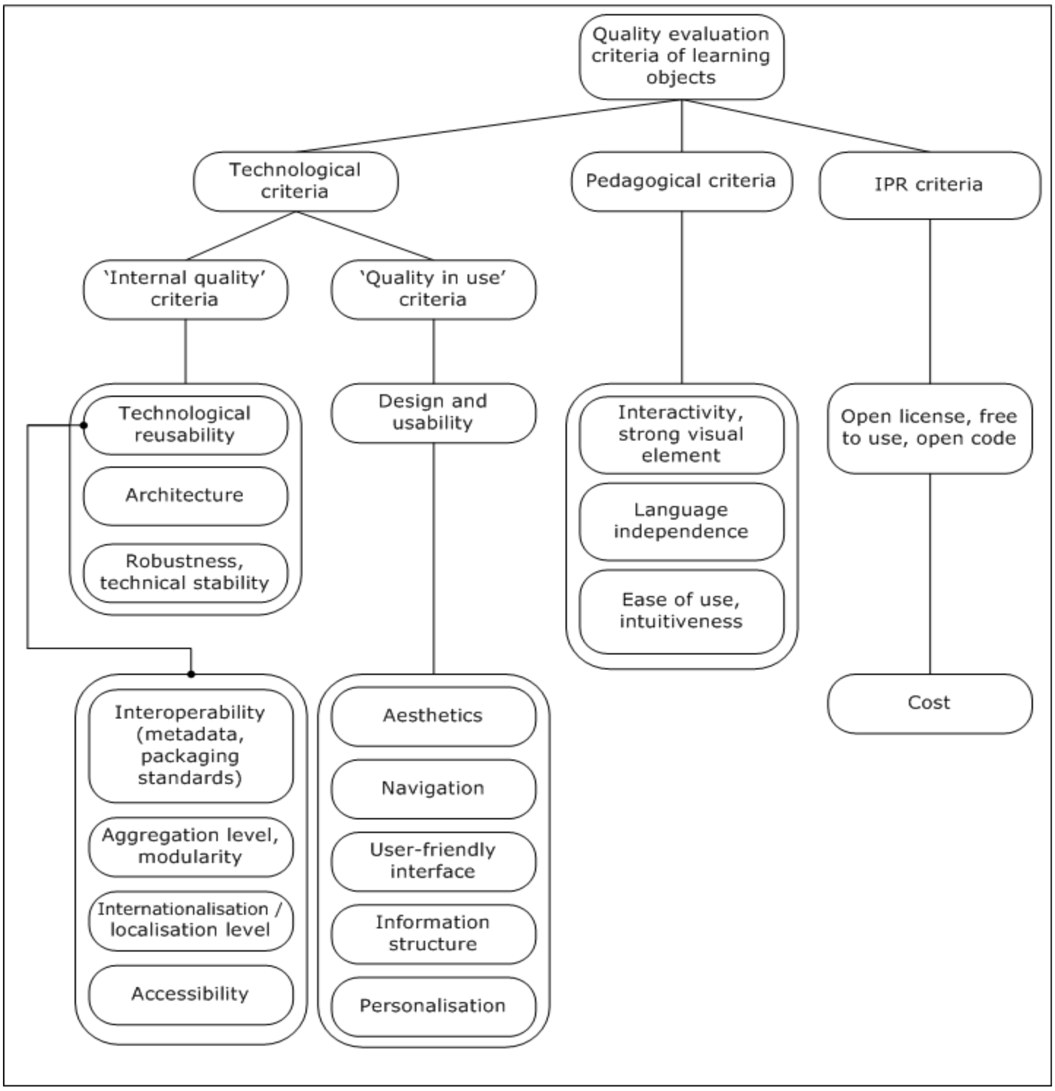

Figure 1: LOs quality evaluation model (criteria tree)

According to the *technological quality criteria classification principle*, we can divide technological quality criteria into 'internal quality' and 'quality in use' criteria of the educational software (e.g., LOs). 'Internal quality' is a descriptive characteristic that describes the quality of software independently from any particular context of its use, while 'quality in use' is evaluative characteristic of software obtained by making a judgment based on criteria that determine the worthiness of software for a particular project (Kurilovas and Dagiene 2009a).

Any LOs quality evaluation model (set of criteria) should provide the experts (decision makers) the clear instrumentality who (i.e., what kind of experts) should analyse what kind of LOs quality criteria in order to select the best LOs suitable for their needs. According to aforementioned technological quality criteria classification principle, 'internal quality' criteria should be mainly the area of interest of the software engineers, and 'quality in use' criteria should be mostly analysed by the programmers and users taking into account the users' feedback on the usability of software (Kurilovas and Serikoviene 2010).

The authors have applied these two principles in their previous papers (Kurilovas and Dagiene 2009a, 2009b, 2009c, Kurilovas and Serikoviene 2010) on technological evaluation of the learning software, and thus have identified a number of LOs technological quality evaluation criteria presented in the technological part of the LOs quality evaluation model (see Fig. 1).

On the other hand, the authors have analysed a number of existing models (sets of quality evaluation criteria) for evaluation of pedagogical quality of LOs, e.g., (Becta 2007, Leacock and Nesbit 2007, MELT 2008, Vargo *et. al.* 2003).

Suitable pedagogical reusability criteria based on MCDA principles (Belton and Stewart 2002) are:

(1) Interactivity, strong visual structure (animations, images and short videos are travelling best).

(2) Language independence or low language dependence (easily translatable) or multilinguality.

(3) Ease of use, intuitiveness.

Intellectual property rights (IPR) criterion should also be considered here (Kurilovas and Bireniene 2010).

The authors' analysis has shown that the model presented in Fig. 1 fits all MCDA criteria identification principles. Taking into account Non-redundancy, Judgmental independence, Balancing completeness and conciseness, Operationality, and Simplicity versus complexity MCDA criteria identification principles, the authors consider that the following eight LOs evaluation criteria should construct the comprehensive LOs quality criteria tree (see Fig. 1):

Technological quality criteria:

'Internal quality' criteria:

(1) Technological reusability:

- Interoperability: Metadata accuracy; Compliance with the main import/export standards (e.g., IMS CP, IMS CC, SCORM 2004).
- Decontextualisation: Is LO indivisible (atomic)? – LO aggregation (granularity) level; Is LO modular (i.e., are the parts of a content item fully functional on their own?).
- Cultural and learning diversity (Adaptability): LO flexibility (LO can be modified, for instance from a configuration file, from a plain text file or because it is provided along with its source code or an authoring tool); LO internationalisation level; LO suitability for localisation.
- Accessibility (design of controls and presentation formats to accommodate disabled and mobile learners): Is LO designed for all?; Compliance with accessibility standards (W3C) (Kurilovas and Dagiene 2009c).

(2) Architecture: Is LO architecture layered in order to separate data, presentation and application logics? (Kurilovas and Dagiene 2009c).

(3) Robustness, technical stability:

- Having help functions that identify common user problems and their solutions.
- Having navigational actions that can be undone.
- Giving quick, visible and audible responses to user actions.
- Allowing the user to exit at any point.
- Not being adversely affected by user experimentation and error. If users do experience an error they should be able to recover quickly and, where appropriate, be informed about the nature of the error (Becta, 2007)

'Quality in use' criterion:

(4) Design and usability (design of visual and auditory information for enhanced learning and efficient mental processing): Aesthetics; Navigation; User-friendly interface; Information structuring; Personalisation (Kurilovas and Dagiene 2009c).

These LOs technological quality criteria are included into a majority of the aforementioned LOs evaluation models. 'Interoperability' and 'Accessibility' criteria being independent criteria in e.g., (Leacock and Nesbit 2007) or (Becta 2007) are included as sub-criteria into 'Technical reusability' criterion in the presented model. There are several reasons for this, e.g., both 'Interoperability' and 'Accessibility' criteria deal with international interoperability standards and specifications, both influence LO technical reusability level in different repositories and platforms, etc. MCDA Non-redundancy principle is applied here.

Pedagogical quality criteria:
(5) Interactivity, strong visual element: e.g., LOs include animations, images, short videos and simulations that are self-explanatory or have just a few text labels or icons/buttons for start, stop, etc.; strong visual structure (MELT 2008).

(6) Language independence: LO is not text-heavy; LOs may have little or no text; or low language dependence (easily translatable); or LOs are multilingual, i.e., LOs have been designed to be language customisable and are already offered in more than one language (MELT 2008).

(7) Ease of use, intuitiveness:

- Users can find their way through the resource almost intuitively; they can broadly understand what is the intended learning objective or topic (MELT 2008).
- LOs provide appropriate guidance, where necessary, for learners and/or practitioners.
- LOs make appropriate assumptions about the ICT skills of users, both learners and practitioners, or provide straightforward guidance on this.
- LOs not present a barrier or impede the learning experience (Becta 2007).

These LOs pedagogical quality criteria are included into the analysed LOs evaluation models (Leacock and Nesbit 2007, Becta 2007, MELT 2008, Vargo *et. al.* 2003).

There are also several criteria included into the aforementioned models. They are: 'Content quality' (Leacock and Nesbit 2007), 'Match to the curriculum', 'Assessment', 'Learner engagement', and 'Innovative approaches' (Becta 2007).

In the authors' opinion, 'Content quality' criterion should not be included into the proposed LOs quality evaluation model. The main reason for this is "a need for a common (more narrow) definition of what is, and what is not a LO" (Paulsson and Naeve 2006). Therefore, since a LO is "any digital resource that can be reused to support learning" (Wiley 2000), we can conclude that scientific content of any LO should be relevant, accurate and trustworthy, in other case the digital resource could not be used and reused "to support learning".

'Match to the curriculum' criterion could be suitable for nationally recognised quality criteria of learning resources, but taking into account the "more narrow definition" (Paulsson and Naeve 2006) of LOs, we should consider only the resources "that can be reused" to support learning (Wiley 2000). Since there are different curricula in different countries, reusable resources should be curriculum independent. Reusable LOs could be often used in other pedagogic situations and learning scenarios that have been planned by LOs authors. Such approach has been, e.g., applied by the author's leaded team in FP6 CALIBRATE project (CALIBRATE 2008) where Lithuanian teachers have been created and implemented their own lesson plans using foreign LOs from LRE.

Criteria such as 'Assessment to support learning' and 'Robust summative assessment' (Becta 2007) often do not fit the LO reusability principle – they are mostly suitable for entire learning courses with high semantic density and aggregation level.

Criteria such as 'Learner engagement' and 'Innovative approaches' are interconnected on the one hand, and are closely related to 'Interactivity' and 'Intuitiveness' criteria included into the proposed model, on the other.

IPR quality criterion:

(8) Open license, free to use, open code: Licensing (clear rules, e.g., compliance with Creative Commons); Economic efficiency – Cost versus Quality taking into account probable LO reusability level (Kurilovas 2007).

3.2 Learning objects quality evaluation methods

The widely used measurement criteria of the decision attributes' quality are mainly qualitative and subjective. Decisions in this context are often expressed in natural language, and evaluators are unable to assign exact numerical values to the different criteria. Assessment can be often performed by linguistic variables: 'bad', 'poor', 'fair', 'good' and 'excellent'. These values are imprecise and uncertain: they are commonly called 'fuzzy values'. Integrating these different judgments to obtain a final evaluation is not evident (Kurilovas and Serikoviene 2010). Therefore, the authors have proposed to use *fuzzy group decision making theory* (Ounaies *et. al.* 2009) to obtain final assessment measures. The fuzzy numbers are: (1) triangular fuzzy numbers, (2) trapezoidal fuzzy numbers, and (3) bell-shaped fuzzy numbers. In the presented paper, the authors use *triangular* and *trapezoidal fuzzy numbers* for evaluating quality and reusability of LOs.

Use of triangular fuzzy numbers

According to (Zhang Li Li and Cheng De Yong 1992), triangular fuzzy numbers (TFNs) are a class of the fuzzy set representation. A triangular fuzzy number is expressed by three real numbers $M = (l, m, u)$; the parameters l, m and u, respectively, indicate the lower, the mean and the upper possible values. TFNs membership functions are as follows:

$$\mu_M(x) = \begin{cases} \dfrac{x-l}{m-l}, & if \quad x \in [l, m], \\ \dfrac{x-u}{m-u}, & if \quad x \in [m, u], \\ 0, & if \quad x \notin [l, u]. \end{cases}$$

Figure 2 illustrates triangular fuzzy numbers.

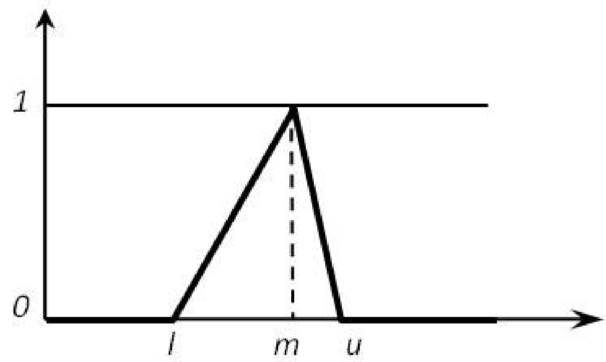

Figure 2: Triangular fuzzy numbers

Conversion of these qualitative values into fuzzy numbers is shown in Table 1.

Table 1: Linguistic variables conversion into triangular fuzzy numbers

Linguistic variables	Triangular fuzzy numbers
Excellent	(0.700, 0.850, 1.000)
Good	(0.525, 0.675, 0.825)
Fair	(0.350, 0.500, 0.650)
Poor	(0.175, 0.325, 0.475)
Bad	(0.000, 0.150, 0.300)

Therefore, in the case of using average triangular fuzzy numbers, linguistic variables conversion into non-fuzzy values of the evaluation criteria should be as follows: 'excellent'=0.850; 'good'=0.675; 'fair'=0.500; 'poor'=0.325; 'bad'=0.150 (Kurilovas and Serikoviene 2010).

The weight of the evaluation criterion reflects the experts' opinion on the criterion's importance level in comparison with the other criteria for the particular needs. For example, for the most simple (general) case, when all LOs evaluation criteria are of equal importance (i.e., we pay no especial attention to LOs reusability criteria), the experts could consider the equal weights a_i = 0.125 according to the normalisation requirement (2).

But if we pay especial attention to LOs reusability criteria, we can, e.g., consider the increased weights for the 1st and 6th LOs quality evaluation criteria (see Fig. 1 and Tables 2, 3 below), because these criteria deal with LOs reusability mostly. In this case, the authors while implementing eQNet have decided to apply increased weights that are twice higher in comparison with the other ones (i.e., 0.2), and all other criteria weights according to normalisation requirement (2) should be equal 0.1.

Lithuanian Physics expert teacher (the co-author of the paper) has applied the presented evaluation model and triangular fuzzy numbers method in eQNet project (see Table 2 below).

A number of probably qualitative reusable Physics LOs have been identified in Lithuanian LOs repositories and evaluated against the model and method presented above (see formula (1)).

There are several examples of these LOs presented in Table 2:

(1) LO_1: Light diffraction (available online at http://mkp.emokykla.lt/imo/lt/mo/330/);

(2) LO_2: Photo effect (available online at http://mkp.emokykla.lt/imo/lt/mo/367/); and

(3) LO_3: Isobar process (available online at http://mkp.emokykla.lt/imo/lt/mo/395/).

Table 2: Results of experimental evaluation of Physics LOs general quality (q) and "travel well" quality (twq) using triangular fuzzy numbers method

LOs evaluation criteria	LO_1q	LO_2q	LO_3q	LO_1twq	LO_2twq	LO_3twq
Technological criteria:						
1. Technological reusability	0.850	0.850	0.850	*0.1700*	*0.1700*	*0.1700*
2. Design and usability	0.850	0.850	0.850	0.0850	0.0850	0.0850
3. Working stability	0.850	0.850	0.850	0.0850	0.0850	0.0850
4. Architecture	0.675	0.675	0.675	0.0675	0.0675	0.0675
Pedagogical criteria:						
5. Interactivity level	0.500	0.500	0.500	0.0500	0.0500	0.0500
6. Language independence	0.850	0.675	0.500	*0.1700*	*0.1350*	*0.1000*
7. Ease of use, intuitiveness	0.850	0.850	0.850	0.0850	0.0850	0.0850
IPR criteria:						
8. Open licence, cost	0.850	0.850	0.850	0.0850	0.0850	0.0850
Evaluation results:	***0.7844***	***0.7625***	***0.7406***	***0.7975***	***0.7625***	***0.7275***

These results mean that LO_1 meets 78.44% quality (q) in comparison with the ideal, LO_2 – 76.25%, and LO_3 – 74.06%. They also mean that LO_1 meets 79.75% "travel well" quality (twq) in comparison with the ideal, LO_2 – 76.25%, and LO_3 – 72.75%.

Therefore, using triangular fuzzy numbers method, one could see that LO_1 is the best alternative (among the evaluated) both from general quality and "travel well" quality points of view.

Lithuanian Mathematics expert teacher (the co-author of the paper) has also applied the presented evaluation model and triangular fuzzy numbers method in eQNet project (see Table 3).

A number of probably qualitative reusable LOs have been identified in Lithuanian LOs repositories and evaluated against the aforementioned model and method (see formula (1)).

There are three examples of these LOs presented in Table 3:

- LO_1: "Coordinate Method" (available online at http://mkp.emokykla.lt/imo/lt/mo/250/);
- LO_2: "Polygon area" (available online at http://mkp.emokykla.lt/imo/lt/mo/431/); and
- LO_3: "Interval Method" (available online at http://mkp.emokykla.lt/imo/lt/mo/316/).

Table 3: Results of experimental evaluation of Mathematics LOs general quality (q) and "travel well" quality (twq) using triangular fuzzy numbers method

LOs evaluation criteria	LO_1q	LO_2q	LO_3q	LO_1twq	LO_2twq	LO_3twq
Technological criteria:						
1. Technological reusability	0.675	0.850	0.675	*0.1350*	*0.1700*	*0.1350*
2. Design and usability	0.675	0.850	0.850	0.0675	0.0850	0.0850
3. Working stability	0.675	0.500	0.675	0.0675	0.0500	0.0675
4. Architecture	0.675	0.500	0.500	0.0675	0.0500	0.0500
Pedagogical criteria:						
5. Interactivity level	0.850	0.500	0.325	0.0850	0.0500	0.0325
6. Language independence	0.675	0.850	0.325	*0.1350*	*0.1700*	*0.0650*
7. Ease of use, intuitiveness	0.850	0.850	0.500	0.0850	0.0850	0.0500
IPR criteria:						
8. Open licence, cost	0.850	0.850	0.850	0.0850	0.0850	0.0850
Evaluation results:	***0.7406***	***0.7188***	***0.5875***	***0.7275***	***0.7450***	***0.5700***

These results mean that LO_1 meets 74.06% general quality (q) in comparison with the ideal, LO_2 – 71.88%, and LO_3 – 58.75%. They also mean that LO_1 meets 72.75% "travel well" quality (twq) in comparison with the ideal, LO_2 – 74.50%, and LO_3 – 57.00%.

Therefore, using triangular fuzzy numbers method, one could see that LO_1 is the best alternative (among the evaluated) from general quality point of view, but LO_2 is the best from "travel well" quality point of view.

These two examples show that the application of the presented model and triangular fuzzy numbers method for evaluation of LOs quality can show both

- Similar results for 'general quality' and 'travel well quality' of LOs (see Table 2), and
- Different results for 'general quality' and 'travel well quality' (see Table 3) of different LOs.

Use of trapezoidal fuzzy numbers

A trapezoidal fuzzy number is a fuzzy number represented by four points as follows: $M = (a, b, c, d)$.

In this case, a membership function can be attached to the level fuzzy function:

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

Figure 3 illustrates trapezoidal fuzzy numbers.

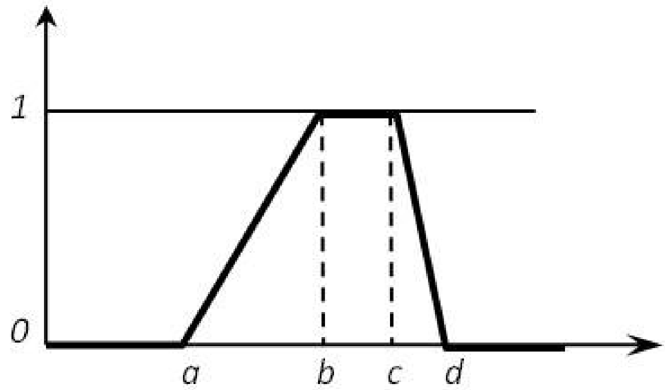

Figure 3: Trapezoidal fuzzy numbers

Conversion of these qualitative values into fuzzy numbers is shown in Table 4.

Table 4: Linguistic variables conversion into trapezoidal fuzzy numbers

Linguistic variables	Trapezoidal fuzzy numbers
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 secondary trapezoidal fuzzy numbers, linguistic variables conversion into non-fuzzy values of the evaluation criteria should be as follows: 'excellent'=1.000; 'good'=0.800; 'fair'=0.500; 'poor'=0.200; 'bad'=0.000. The results of evaluation of quality of the same Physics and Mathematics LOs identified in Lithuanian LOs repositories using trapezoidal fuzzy numbers and the same approach to the weights of criteria are presented in Tables 5 and 6 below.

Table 5: Results of experimental evaluation of Physics LOs general quality (q) and "travel well" quality (twq) using trapezoidal fuzzy numbers

LOs evaluation criteria	LO_1q	LO_2q	LO_3q	LO_1twq	LO_2twq	LO_3twq
Technological criteria:						
1. Technological reusability	1.000	1.000	1.000	*0.2000*	*0.2000*	*0.2000*
2. Design and usability	1.000	1.000	1.000	0.1000	0.1000	0.1000
3. Working stability	1.000	1.000	1.000	0.1000	0.1000	0.1000
4. Architecture	0.800	0.800	0.800	0.0800	0.0800	0.0800
Pedagogical criteria:						
5. Interactivity level	0.500	0.500	0.500	0.0500	0.0500	0.0500
6. Language independence	1.000	0.800	0.500	*0.2000*	*0.1600*	*0.1000*
7. Ease of use, intuitiveness	1.000	1.000	1.000	0.1000	0.1000	0.1000
IPR criteria:						
8. Open licence, cost	1.000	1.000	1.000	0.1000	0.1000	0.1000
Evaluation results:	***0.9125***	***0.8875***	***0.8500***	***0.9300***	***0.8900***	***0.8300***

These results mean that LO_1 meets 91.25% quality (q) in comparison with the ideal, LO_2 – 88.75%, and LO_3 – 85.00%. They also mean that LO_1 meets 93.00% “travel well” quality (twq) in comparison with the ideal, LO_2 – 89.00%, and LO_3 – 83.00%.

Therefore, using trapezoidal fuzzy numbers method, one could see that LO_1 is the best alternative (among the evaluated) both from general quality and “travel well” quality points of view. The results are similar in comparison with the ones obtained using triangular fuzzy numbers.

Table 6: Results of experimental evaluation of Mathematics LOs general quality (q) and “travel well” quality (twq) using trapezoidal fuzzy numbers

LOs evaluation criteria	LO_1q	LO_2q	LO_3q	LO_1twq	LO_2twq	LO_3twq
Technological criteria:						
1. Technological reusability	0.800	1.000	0.800	*0.1600*	*0.2000*	*0.1600*
2. Design and usability	0.800	1.000	1.000	0.0800	0.1000	0.1000
3. Working stability	0.800	0.500	0.800	0.0800	0.0500	0.0800
4. Architecture	0.800	0.500	0.500	0.0800	0.0500	0.0500
Pedagogical criteria:						
5. Interactivity level	1.000	0.500	0.200	0.1000	0.0500	0.0200
6. Language independence	0.800	1.000	0.200	*0.1600*	*0.2000*	*0.0400*
7. Ease of use, intuitiveness	1.000	1.000	0.500	0.1000	0.1000	0.0500
IPR criteria:						
8. Open licence, cost	1.000	1.000	1.000	0.1000	0.1000	0.1000
Evaluation results:	***0.8750***	***0.8125***	***0.6250***	***0.8600***	***0.8500***	***0.6000***

These results mean that LO_1 meets 87.50% general quality (q) in comparison with the ideal, LO_2 – 81.25%, and LO_3 – 62.50%. They also mean that LO_1 meets 86.00% “travel well” quality (twq) in comparison with the ideal, LO_2 – 85.00%, and LO_3 – 60.00%.

Therefore, using trapezoidal fuzzy numbers method, one could see that LO_1 is the best alternative (among the evaluated) both from general quality and “travel well” quality points of view. The general quality evaluation results are similar, but “travel well” quality evaluation results are a little bit different in comparison with the ones obtained using triangular fuzzy numbers.

In real life situations a teacher is the only suitable expert to decide on quality of LOs, and, therefore, on purposefulness to use these LOs in his / her teaching process in particular school.

In the analysed cases it is clear that Physics teacher should choose LO_1 as the best alternative both from general quality and “travel well” quality points of view.

Mathematics teacher should choose LO_1 as the best alternative from general quality point of view, and either LO_1 or LO_2 – from “travel well” quality point of view since the difference between “travel well” quality evaluation values of LO_1 and LO_2 is very small.

4. Conclusion and recommendations

The research results presented in the paper show that the complex application of the principles of multiple criteria decision analysis for identification of quality evaluation criteria, technological quality criteria classification principle, fuzzy group decision making theory to obtain final evaluation measures, and normalisation requirement for the weights of evaluation criteria, as well as triangular and trapezoidal fuzzy numbers methods for LOs quality optimisation are (1) applicable in real life situations when schools have to decide on purchase of LOs for their education needs, and (2) could significantly improve the quality of expert evaluation of LOs by noticeably reduce of the expert evaluation subjectivity level.

The experimental evaluation results show that the proposed scientific approaches are quite objective, exact and simply to use for selecting the qualitative LOs alternatives in the market.

On the other hand, the proposed LOs "travel well" quality evaluation approach is applicable for the aims of eQNet project in order to select "travel well" LOs from LRE or elsewhere to use them in the other education contexts and countries.

Therefore, these approaches have been recommended by the authors to be widely used by European policy makers, publishers, practitioners, and experts-evaluators both inside and outside eQNet project to evaluate quality and reusability level of LOs.

5. Appendix

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