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Exploring the Micro, Meso and Macro

Navigating between dimensions in the digital learning landscape

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Introduction

The demand for people with new, enhanced skills is growing. The volume of information produced and shared in all fields is overwhelming. Building the data economy became part of the EU Digital Single Market. Powerful and sophisticated ICT is part of everyday life, and the world of learning is not an exception. Pressure is on all players of the online education community to keep up with new learning solutions, and better supply the skills currently demanded by growing economies.

Open Education continues its success, providing radical advances in knowledge acquisition, sharing, distribution, and improving business models. Digital credentials and open badges are the new currencies which are beginning to transform the economic models in education.

Social and economic tensions continue to raise the issues of scalability, the micro-credentialling of education, training and skill development processes. Practitioners and stakeholders are eagerly seeking right approaches to providing learning opportunities, and many scholars are researching holistic answers.

Micro, meso and macro aspects provide an interesting range of lenses for considering the problem. These aspects may be applied in a general sense, distinguishing between the learning of individuals, learning at the institutional or group levels through a meso lens, and the learning of organizations or societies directed through policies through the macro lens.

Navigating these dimensions are the reshaping of digital pedagogy and online instructional design; the social elements including digital societal mechanisms and the position of the individual in our new era. We have need of systematic awareness and research in the critical era of sustainable socio-cultural aspects as they relate to learning.

Eoropean Union initiatives emphasize solutions to emerging needs and seek to improve competitiveness and professional development; enhance cross-sectional skills; and fuel the engines of social innovation – creativity, entrepreneurship, critical thinking and problem solving.

The EDEN 2018 Genova Conference aims to respond to contemporary needs by:

- tracking and demonstrating evidence about the mechanisms and value chains across micro-, meso- and macro-learning
- exploiting the socio-cultural specifics related to the granularity of learning
- digging deeper into finding viable, achievable and scalable solutions
- learning more about didactical design through peer learning and scholarly observation
- discussing structural and operational questions of collaborative - social technologies

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DEVELOPING COMPETENCE ASSESSMENT SYSTEMS IN E-LEARNING COMMUNITIES

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Abstract

This paper presents the development of systems for helping a community of educator to share and reuse digital learning materials, and for enabling learners to enhance their online formative assessment. This educational design research is conducted iteratively toward dual goals: fostering competency-based assessment and proposing new structured knowledge for practitioners facing similar issues. Two main products respectively related to the research goals are presented, to be used as the core of the systems integrated to virtual learning communities: a methodology for planning automatic assessment units as parts of adaptive learning paths, and an ontological scheme about the relations between cognitive processes and disciplinary contents defining learning objectives. The outcomes are discussed considering results obtained from some experimentation.

Introduction

The spread of Technology Enhanced Learning and the growth of Virtual Learning Communities (VLCs) rely deeply on the efficiency of the processes of finding, sharing, reusing, and analysing educational contents. Considering the scope of automatic assessment, the present research proposes methodologies and tools for supporting the assessment of competences in VLCs. The research involves the development of a system integrated in Learning Management Systems (LMSs) hosting the VLC: it serves as engine for the automatic generation of digital maps from the collection of resources shared by the community of instructors. The maps will generate “learning object trajectories” (or “learning paths”), which are paths composed of nodes and edges: a node is a reference to a resource available in the LMS, while an edge between two nodes is created by matching commonalities between learning intentions and success criteria related to the two learning objects identified in the nodes. The system’s usage will be twofold: to support teachers to design e-learning units for competence assessment and to enhance their usage by the students for self-assessment. More specifically, the system will serve as and information retrieval system for the instructors, and as a recommender system for the students. It will be *adaptive* in the sense that it will provide materials according to success criteria compared to students’ results. Furthermore, it will provide the community of teachers with aggregate analyses on the results of the community of students, to foster discussions on the effectiveness of the materials and methodologies proposed among the community of instructors. This paper presents the development process and the results obtained from a mixed qualitative and quantitative analysis conducted by our University in few projects.

State of the art

There is no universally shared definition of competence (or *competency*). *Competence* means the ability to cope with a task, or a set of tasks, managing to activate and orchestrate internal, cognitive, affective and willful resources, and to use the external resources available in a coherent and fruitful way. Series of progressive specific objectives can compose the set of targets toward the competences expected at the end of a scholastic path. Several taxonomies have been published and largely used for the design and interpretation of both learning objectives and achievement tests. Examples are Bloom's Taxonomy (1956) and Anderson and Krathwohl's revision of Bloom's taxonomy (2001). Focusing on mathematics education, and assuming that all cognitive levels could be tested using objective test questions (Beevers & Paterson, 2003), the use of an Automatic Assessment System can efficiently support the preparation of activities aimed at obtaining, managing and monitoring performance results to validate the achievement of learning objectives (Barana & Marchisio, 2016; Barana, Marchisio, & Rabellino, 2015). The extension of the taxonomical models for automatic assessment can be enriched if implemented as semantic technologies. Taxonomy differs from other formalizing knowledge resources by their degree of formalization (Navigli, 2016). Higher-formalized instrument are Ontologies, which have been used for many different tasks (Elizarov et al., 2014). Considering the contest of virtual communities, semantic technologies integrated with automatic assessment tools can have great impact on formative assessment. Formative assessment is the way learners use information from judgments about their work to improve their competence. Since the nineties, the concern about formative assessment has grown to cover one of the major issues in the educational research. Paul Black and Dylan Wiliam conceptualized formative assessment through five key strategies (2009). The present research is conceived to implement Black and William' five strategies into five innovative actions in VLCs. The implementation strongly relies on Natural Language Processing (NLP) techniques. The work is carried within communities of practice that have certain characteristics of innovativeness, responsiveness to evidence, connectivity to basic science, and dedication to continual improvement (Spector et al., 2014). The research seeks to understand how designs function under different conditions and in different contexts, which however share the common characteristic of constituting a Virtual Learning Community (VLC) (or a "community of communities") (Pardini et al., 2013). A VLC is a system where

- instructors (experts in the disciplines to be learned) manage one or more courses dedicated to a group of learners;
- tutors (discipline and ICT experts) help instructors in experimenting innovative methodologies for teaching, creating digital materials, peer collaboration, sharing resources and best practices, using advanced tools integrated to the LMS that hosts the online courses;
- instructors and tutors agree upon a framework of competences expected to be achieved by the learners at the end of the learning process.

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The research is conducted with VLC at local, national and European level. The VLCs involved have in common the technologies available: a Virtual Learning Environment (VLE) integrated with an Advance Computing Environment an Automatic Assessment System and a web conference system. The asset developed and proposed has proved to be an essential tool both to allow collaborative learning among teachers and to promote problem posing and problem solving as learning methodologies, to the extent of revolutionizing the teaching of scientific subjects (Brancaccio et al., 2015), also in different European countries (Barana et al., 2017; Brancaccio et al., 2016). It is also effective for reducing scholastic failures (Barana & Marchisio, 2015).

Methodology

The research investigates the possibility to create an innovative *information retrieval* (for instructors) and *recommender* (for learners) system. The system shall enable a process for:

- automating the organization of materials for automatic assessment according to learning objectives;
- support instructors in retrieving materials from a search by natural language descriptions;
- adaptively providing materials to the learners for activating a process of formative assessment;
- aggregate students' results to foster instructors' discussion on top of advanced analysis.

The system is designed to automatically organize shared digital materials providing that the creators publish their contents jointly with natural language descriptions of the intended learning objectives. To build such system integrated to an LMS, two outputs have been created: (a) a model for the association of learning materials with natural language descriptions related to the implied competences; (b) an ontology for enabling the automatic interpretation of the descriptions.

As primary practical contribution, the methodological principles for descriptors are used in several projects at national and local scale by instructors and tutors working within VLCs. The research involves a mixed qualitative and quantitative analysis. The methods used are: observations, synchronous online interviews, online questionnaires, document analyses, online content analysis, web-based experiments. The research methodology follows the three-interacting phases model of McKenney and Reeves (Spector et al., 2014): analysis/orientation, design/development and evaluation/retrospective phases. Furthermore, it is characterized as follows:

- *Adaptive*: the intervention and research design are adjusted in accordance with insights emerging from inquiries on instructor.
- *Grounded and oriented by theory*: firstly, the work is guided by educational theory about formative assessment, learning tasks and cognitive processes, empirical findings from learning communities, and craft wisdom generated by investigation. Moreover, the design and development work is undertaken to contribute to a broader scientific

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understanding of cognitive processes activated during online assessment, and how it can contribute to evidence competence.

- *Interventionist*: the experimentation is undertaken to make a change in the particular educational context of virtual learning communities for STEM education.
- *Collaborative*: the research requires the expertise of multidisciplinary partnerships, instructors, experts in education and experts in Computer Science and in particular of NLP.
- *Pragmatic*: it is concerned with generating ontologies usable by the semantic web community, and solutions for automatic formative assessment.
- *Iterative*: research evolves through multiple cycles of design, development, testing and revision.

Associating of learning materials to natural language descriptions related to competencies

A triple of student-centred descriptors (*Performance*, *Requisites*, *Objectives*) is proposed to strengthen instructors' reasoning on the selection of contents, development of an instructional strategy, and construction of tests and other instruments for assessing competencies. The triple to be included as metadata of a shared material for automatic assessment is defined as follows.

- *Performance* (also known as *instructional objectives*, *behavioural objectives* or *learning objectives*) is a specific statement of the observable behaviour required to who attempts performing the material.
- *Requisites* (or *prerequisites*) states the instructor's belief of the necessary and sufficient condition to attempt performing the material.
- *Objectives* (or *goals*) specifies what learners are required to be able to do as a result of the learning activity related to the material.

Performance is proposed to activate a reflection on the structure of the materials used online, therefore should be useful to the teacher both in the design phase, and during the research and afterwards. A well-written performance should meet the following criteria: describe a learning outcome (what the student will be able to do, that *can be observed* directly), be student-oriented (describing the conditions under which the student will perform the task), be observable (indicating criteria for evaluating student's performance). Optionally, a degree of mastery needed can be explicated. *Requisites* indicates the learning goals that should be acquired before attempting to answer. It connects to the essential objectives that are supposed to be mastered. *Objectives*, differently from *Performance*, does not depend on the type of response field. The statement should not simply describe a list of topics, that being too abstract, too narrow, nor being restricted to lower-level cognitive skills.

Ontology for enabling the automatic interpretation of natural language descriptions

Materials' descriptors express which student's performance is required in terms of activated cognitive processes and types of knowledge on which these processes operate. The adoption of a taxonomic model is proposed as the main reference effecting both instructors and learners:

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during the design phase, it is important to "space" in the definition of learning tasks; moreover, automatically subsuming cognitive processes and knowledge types implicit in a material is the key for adaptively advising students with variegated resources. The ontological implementation of Anderson and Krathwohl's taxonomy, to be used together with an Italian translation of OntoMath^{PRO}, is proposed for clustering resources according to their similarity with respect to the thinking skills and types of knowledge involved. The possibility of matching similarities among digital materials is crucial for building mapped data sets of entities and relationships across entities useful for automatic formative assessment strategies.

Anderson and Krathwohl proposed a classification of cognitive processes and knowledge types: 11 types of knowledge organized into 4 categories (Facts, Concepts, Procedures, Metacognition), and 19 basic processes organized into 6 categories (Remember, Understand, Apply, Analyse, Evaluate, Create) ordered by ascending cognitive complexity. Cognitive complexity should not be confused with difficulty: for each cognitive process it is possible to design material that vary from easy to challenging. In fact, the defined epistemological categories are deeply interrelated and dependent on each other: cognitive processes activated in resolving learning tasks often operate in a coordinated manner. Cognitive processes "operate" on types of knowledge, which are considered both as objects and as a product of cognitive processes.

Considering Anderson & Krathwohl's taxonomy, a material can be linked to a set of concepts' couples referring to a 4×6 matrix: the first dimension of the matrix represents the types of knowledge while the second dimension represents the cognitive processes involved. The connection between a material and a matrix's element is established by identifying cognitive processes and knowledge type from its content or metadata. Clues to be found are the following:

- one or more *action verbs*, each being a synonym of a single cognitive process;
- one or more disciplinary terms, each related to a single knowledge concept;

The presence of an action verb (leaf element) is considered as an indicator of a cognitive process as defined by Anderson & Krathwohl.

Considering the previous observations, this research uses an ontological version of Anderson & Krathwohl taxonomy, to be integrated with the domain-specific OntoMath^{PRO} ontology (Elizarov et al., 2014). OntoMath^{PRO} is a bilingual (Russian/English) ontology of mathematical knowledge, geared to be the hub for math knowledge on the Web of Data. The developers share the sources with the Semantic Web community. This research proposes the adoption and translation of OntoMath^{PRO} also in the Italian panorama. The modelling principles for building Anderson & Krathwohl's ontology follow the ones of OntoMath^{PRO} ontology:

- *Only classes, no individuals.* Since the ontology provides a linguistic resource for text processing, individuals shall be found in concrete occurrences of named entities in descriptors.

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- *ISA vs. whole-part*. Since there are only classes instead of individuals, hierarchies are modelled in accordance with ISA relation. Whole-part semantics is expressed through ISA relation considering its interpretability according to the set theory.
- *Validating classes and relations*. Terms to be added to the ontology require a reference from a refereed publication. Establishing correct relation instances relies on their validation by experts involved in the development.
- *URI naming convention*. The ontology is bilingual (Italian/English), Italian and English labels and comments are added for each concept, providing respectively their human-readable terminology and description. Surrogate URIs are used.
- *Multiple inheritance*. Multiple inheritance with respect to ISA-relationships is permitted.
- *Synset as label*. Synonyms are represented by labels of the same class.

Results and discussion

The model for associating natural language descriptions was firstly experimented by two experts. A first collection of 196 digital *units* for automatic assessment was selected from the group of problems created with Maple TA by secondary school instructors and shared within the Italian community of "Problem Posing and Solving" (Barana et al., 2018). The units were extracted from 98 questions for automatic assessment: a *unit* is identified as a response field and the text that precedes it. The questions belong to "disciplinary" groups, which give the following partition on the collection of units: Contextualized problem about Algebra (4), Monomials (68), Polynomials (38), Special products (24), Contextualized problem about Probability (7), Statistics (36), Probability (13), Contextualized problem about Statistics (6). This 8-feature partition (that will be referred as D) is compared with the results from a clustering algorithm operating on the PRO descriptors, setting to 8 the number of clusters to be generated.

The clustering algorithm is executed on the similarity matrices constructed by calculating the similarity for each pair of vectors representing respectively Performance (P), Requisites (R) and Objectives (O) of each unit. The process is done for the first author (1) and the second author (2). To construct a vector from an input string representing a descriptor, the following phases are performed: tokenization, stop words removal, stemming, bag-of-words representation. The corpus of vectors is used to initialize the *transformation model*. The "training" consists in going through the supplied corpus once and computing document frequencies of all of its features. The transformation model is used to convert any vector from the bag-of-words representation to the representation based on the term frequency–inverse document frequency statistic (tf-idf). The similarity matrix is constructed by calculating the cosine similarity for each pair of vectors. Mini Batch k-Means is the clustering algorithm chosen (Pedregosa et al., 2011). It returns a list of 196 labels: each unit is labelled with one out of k clusters, where k (set to 8) is the number of clusters to be generated.

Clusterings generated from different collections of input strings are compared as follows, in two experiment phases. Firstly (phase 1), the clustering process was repeated 10 times following the previously described phases, setting to 8 the number of clusters that the Mini Batch k-Means

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algorithm has to generate. To estimate the correlation between different clusterings, the v_measure homogeneity metric is used, which expresses how successfully homogeneity and completeness criteria have been satisfied between two clusterings (Rosenberg & Hirschberg, 2007). The experiment was repeated (phase 2) attempting *noise reduction* using the structured ontological knowledge. The parsing step is affected by the following rules for tokens' filtering:

1. Words that appear in less than 2 input strings are filtered out.
2. Words that appear in more than the half of the input strings are filtered out.
3. Words are kept regardless the previous rules, if they belong to the set of concepts contained in the ontologies.
4. After the previous rules, only the first n most frequent words are kept.

These rules are proposed to enhance the influence of semantically relevant concepts. The experiment was repeated with the value of n between 7 and 15 in steps of 2. The range for number n was chosen considering the average lengths of vectors. On average, the length of vectors generated from Requirements and Objectives is 6. Considering the Performance, the value of the length of the vectors generated it is 14 for the first author and 10 for the second author.

Figure 1 shows the mean of the v_measure values obtained comparing each of the 6 clusterings generated from the units' descriptors of each given author (1P, 1R, 1O, 2P, 2R, 2O) to respectively the "ground truth" labelling by disciplinary area (D): the first experiment results are represented as dots on the line, while the results from the experiment repetitions for different values of n are represented as bars. The standard deviation values are about two orders of magnitude smaller than the means.

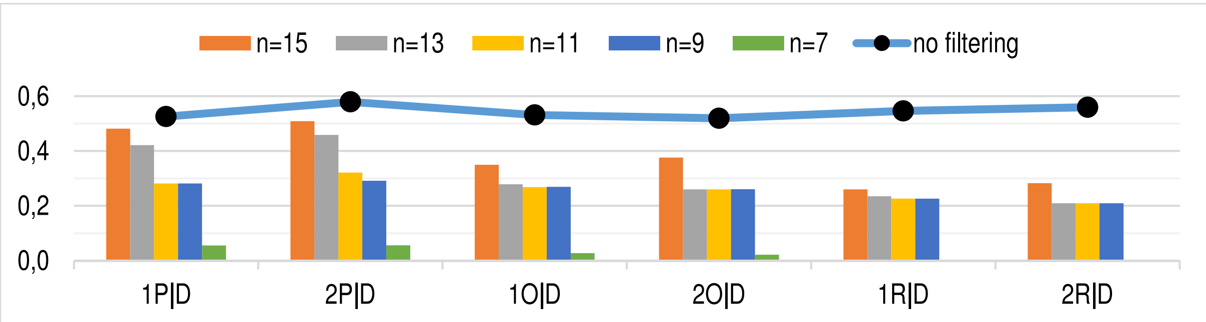

Figure 1. Mean values of the v_measure comparing 1P, 1R, 1O, 2P, 2R, 2O to D, from phase 1 and phase 2.

The results from the two authors tend to reach an approximate level of symmetry, which suggest that a good level of inter-annotation agreement can be achieved from different authors. Phase 1 results show that there is high mutual information among each pair of clustering. The v_measure mean values decrease with the decreasing of n, Performance is the only descriptor which maintain alignment with the "disciplinary" labelling for values of n close to its average vector length. Phase 2 results suggest that filtering enables to generate clusters which express concepts slightly different from the disciplinary grouping. The D clustering was generated by the *questions* partition. Using an ontology can effectively extract meaningful terms referring to concepts more related to the descriptors. Adopting ontologies as semantic-proxies will enable to capture those semantic related concepts.

The model for associating natural language descriptions is also experimented with instructors. Teachers, tutors, and experts are involved in creating new collection of materials whose design starts from the PRO descriptors. Those will be tested with similar clustering analysis. Before explaining to a group of 26 teachers the PRO methodology, they were asked to submit answers to a questionnaire inquiring whether they think about similar design aspects before starting to realize a question (*design* phase), during the creation (*realization* phase), in the phase of administration to the students (*use* phase). Table 1 shows that teachers' dedication to the specification of descriptors while designing materials is natural (Likert scale from 1 to 5).

Table 1: mean and standard deviation to the answers from the questionnaire

Question	Phase	Mean	Std dev.
How much do you reflect on the way in which the question allows you to measure the achievement of the objectives set in the following phases?	design	3.926917566	0.755928946
	realization	3.844344152	0.683461909
	use	2.734386367	1.305838972
How much do you reflect on the requirements necessary to answer a question in the following phases?	design	3.598758769	0.920908553
	realization	3.51227498	0.890870806
	use	3.0873379	1.083791112
How much do you reflect on the requirements necessary to answer a question in the following phases?	design	4.066593604	0.773717943
	realization	3.759259106	0.832993128
	use	3.019007314	1.160576915

Conclusions

The investigation continues collaborating with various University projects activated with the different VLCs at local, national and European level. Qualitative analysis on these materials helps to refine the methodology. The system's development continues with the implementation of a web-based tool integrated to the LMS hosting the VLCs involved. This will lead to experimenting the system with students.

The research project is part of a three-year PhD program in apprenticeship, in Pure and Applied Mathematics, conducted in partnership with leading providers of software based on Computer Algebra System engine.

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