Designing a Mediation Vocabulary for Authoring Learning Analytics

Patricia Charlton, Sokratis Karkalas and Manolis Mavrikis
London Knowledge Lab, Institute of Education, University College London, London, U.K.

Keywords: Education, Designing a Mediation Vocabulary, Knowledge Representation, Feedback, Learning Analytics, Knowledge Integration.

Abstract: This paper provides a knowledge representation process for authoring of learning experiences that capture feedback designed in the context of learning environments. The paper reports on a year long study with designers who are creating mathematical teaching and learning resources as part of an EU project (M C Squared). In this paper we examine the knowledge representation process we used in design and creation of a mediation vocabulary. The model to be designed has to provide different layers of 'knowledge integration' and thus offers insights into the importance of knowledge mediation in the emergence of new learning environments and experiences. Hence, authoring of designs and feedback through use of ontologies to form part of the annotating of the learning activities. The annotations form part of the context to be used as part of the learning analytics.

1 INTRODUCTION

The M C Squared EU (http://www.mc2-project.eu) project is researching into and creating digital teaching and learning resources for secondary school mathematics. The core focus of the project is to investigate and evaluate social creativity and creative mathematical thinking (Bokhove et al., 2014).

Part of the objective of the project is to support authoring of the activities by the designers and teachers. Authoring learning activities is not new and there are many tools and attempts to support this. However, there are number of problems with authoring systems (a) they only work for very specific tasks, (b) the tools often require considerable technical knowledge, such as the teacher/designer needing to program complex rules and (c) they burden the teacher with extra work load that seldom provides the desired insights.

The increase in the use of e-learning activities has brought with it the logging of data resulting in the development of learning environments and tools to support learning analytics.

The definition of learning analytics set out in the call for papers of the first international Conference on Learning Analytics and Knowledge (LAK 2011) and adopted by the Society for Learning Analytics Research (SoLAR): *"Learning analytics is the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs."*

The definition is typically coupled with two assumptions: that learning analytics makes use of machine-readable data, and that its techniques can be used to handle data in ways that would not be practicable to deal with manually.

The rationale behind the authoring tools for feedback and data analytics is that both teachers and learners require support from different perspectives. While students require support when interacting with the learning activities, teachers need to know when and how to intervene as well as how the learning activities are being used. Lastly both teachers and designers can benefit from the availability of data as it provides potential to lead to evidence about the student's learning and eventually redesign of teaching and learning activities based on this evidence.

The use of an ontology was designed to reduce the overhead in authoring of activities and to potentially improve the value of learning analytics through the added context. The approach we use to build the ontology draws from previous experience of the Learning Designer project (Laurillard et al., 2013). In the learning designer project we developed an ontological model to automate the annotation of learning designs.

Charlton, P., Karkalas, S. and Mavrikis, M..
Designing a Mediation Vocabulary for Authoring Learning Analytics.
In *Proceedings of the 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K 2015) - Volume 2: KEOD*, pages 223-230
ISBN: 978-989-758-158-8

This study provides the design process used to develop an ontology to model the vocabulary for authoring feedback to students. The analytics engine uses the same vocabulary terms set by the designers when providing results back to the designer.

In this paper we examine the knowledge representation process used in the design and creation of a mediation vocabulary. The model to be designed has to provide different layers of ‘knowledge integration’ and thus offers insights into the importance of knowledge mediation in the emergence of new learning environments and experiences. This approach addresses authoring of learning activities. The ontology represents the vocabulary terms used for both authoring learning activities and for viewing the results of student engagement.

2 BACKGROUND

2.1 Learning Design and Instructional Design Theory

The development of “Learning Design” has links with Instructional Design theory. The recognition of the need to make theoretical findings readily available to practitioners led to extensive work on Instructional Design Theory (Reigeluth, 1999), which attempted to make learning theories more operational. However, the later focus on “constructivist” theories of learning presented more of a challenge to an operational approach.

Learning Design emerged as the realisation that the constructivist pedagogical theories were not easily embedded in the practice of teaching (Jonassen, 1994). The emphasis on what learners were doing, and how to support their activities, was much less constrained by constructivism, and therefore created a degree of uncertainty about the way it would work in specific contexts. This dependence on the context in which learning takes place required an approach to teaching based on design principles rather than pre-defined instructional sequences (Oliver et al., 2002). There have been attempts to offer “toolkits” or software to enable ease of entry into pedagogic design and support non-specialists in engaging with learning theories. Despite the effort, existing e-learning systems and authoring tools have limitations in respect of support provided and usability. They do not accommodate the needs of teachers who increasingly look for more intelligent services and support when designing instruction in order to avoid cognitive overload (Mizoguchi and Bourdeau, 1999).

In previous research, the authors had found for designers of learning, developing a tool that supported learning design vocabulary mediated the process of authoring designs, sharing their designs more effectively and adopting and modifying designs by others (Charlton et al., 2012; Laurillard et al., 2013). A key finding of the Learning Designer project (Charlton et al., 2012) was the representation of learning design knowledge as an explicit vocabulary supported the creation of learning designs by designers. The vocabulary is an approximation of the concepts used by designers. The knowledge constructs of a learning design used the shared vocabulary that acted as mediation of knowledge between the designers. The vocabulary captured meaning that was relevant to the designers. This reduced the burden of design sharing and thus facilitates design re-use.

2.2 Use of Ontologies in Annotation

Ontologies are one of the most important technologies proposed in the context of the semantic web. A frequent use of an ontology integrated into science systems is to support formal information retrieval of domain concepts and related content.

One of the most successful projects in use of ontologies in science is the Gene Ontology project (http://www.geneontology.org). It develops and uses a set of structured, controlled vocabularies for community use in annotating genes, gene products and sequences.

The mediation vocabulary use in the design of learning activities in authoring feedback is similar to both the Gene Ontology project and the learning designer project. It is the annotation use of mapping a term in text selected by the designer to the corresponding concept in the ontology. For the M C Squared project ontologies are created and go a step further. The annotations formed from the design form part of the student’s learning context that is shared back to the designers that now includes the student’s use.

The students’ interaction creates a change to the sequences and is in the student’s learning pathway. The learning designer project and M C Squared project differ from the Gene Ontology project is the artefact itself. The instance of every use creates another artefact (in this case the use of a c-book creates new insights about the c-book) to be evaluated within the context of the original design. It is a dynamic changing artefact and the annotations

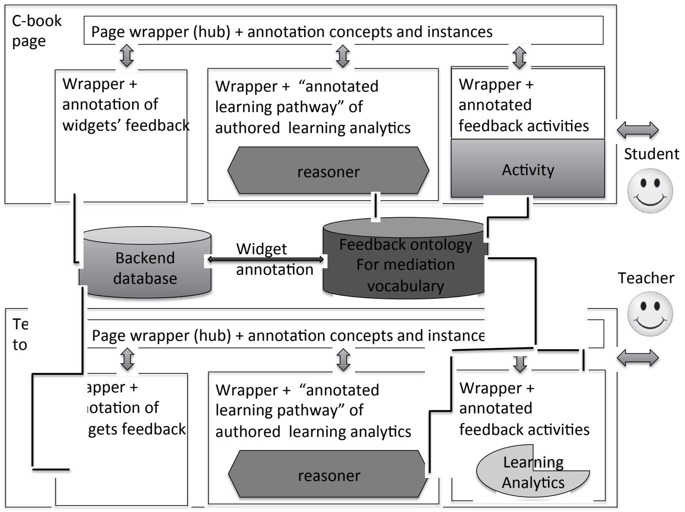

Figure 1: The mediation vocabulary for authoring feedback.

structured by the ontology model of the original artefact provides a reference point for comparison. So how the activities are used, revealed through these annotations of design and student usage unveil the authored analytics of learning in context and thus offer a potential paradigm shift for both design and use of learning analytics.

2.3 Design Considerations

While the ontology model designed and used to automate the annotation process of learning activities is not necessarily complex from an AI perspective, other aspects required in order to incorporate its use effectively are not so straightforward. Essentially, neither a pure knowledge engineering nor a software engineering approach is sufficient in the creation of a mediation vocabulary. In fact designers and developers of an ontology for education systems and AI driven education systems rarely consider this role. The models are either used only as part of design (implementation is never used) or are hidden only given partial access to the model, if at all. Other education systems that enable rich authoring may expect designers to understand too much technical aspects of the tool e.g. formulating rules and program procedures and content management focus (e.g.VLEs) This layer of technical engagement distracts the designer from focusing on creating learning activities. This increases barriers to pedagogical annotation and reduces the possibility of sharing these activities in communities.

Before going into details about the methodology used and findings from the study we examine aspects of the project context that needs to be considered.

2.3.1 Domain of Design

While the learning activities are about mathematics in secondary school the domain focus is about creative mathematical thinking. The designers are creating activities that they categorise as potentially fostering creative mathematical thinking by the learners. The design of the authoring vocabulary of the activities will be formed around a set of formal creative concepts.

Similar to the learning designer the vocabulary needs to be 'good enough' and map to the designer's internal model of design concepts to facilitate the authoring of creative mathematical thinking for their students.

2.3.2 Learning Analytics Platform Integration

Current platforms with learning analytics functionality only support the common form of analytics that of task completion analysis, correct answers and time spent on task. They do not support 'dynamic' context of student feedback that we are referring to and the authoring of this feedback (Charlton et al., 2013).

The mediation vocabulary will need to facilitate the integration of 'relevant data' between the different components used when designing learning activities, support the feedback process, form part of annotating the student's pathway and be part of the data queried for retuning the analytics visually. This reflects the dilution of the distinction between data management and data analysis in order to contextualise the learning experience effectively.

2.3.3 C-book and Vocabulary of Creativity

A core concept of the project is the ‘c-book’. The c-book is a set of learning activities for learning about mathematics. A c-book is formed as a digital interactive book. The ‘c’ stands for creativity. All c-books are designed using social creativity process and share an aim of fostering creative mathematical thinking (CMT) of students (Ruthven, 2008). The shared vocabulary across the project and community of interests is focussed on social creativity and creative mathematical thinking (Silver, 1997; Leikin, 2009). The core model is on supporting the annotation of learning activities with creativity concepts defined, understood and shared by the community.

The M C Squared system (Karkalas et al., 2015) is based on a generic framework that enables seamless integration of complex learning objects with e-book platforms. Authors can use the system to dynamically query learning objects, identify elements of interest and configure data logging, learning analytics and intelligent support.

In Figure 1 we illustrate extending M C Squared architecture to include mediation vocabulary for authoring learning analytics and student feedback through the annotation process. It is distributed across the c-book components.

The pilot study investigated authoring vocabulary requirements for the designers using a design-based methodology. To capture the insights and expert design knowledge we used ‘role play’ - thinking aloud strategy to uncover the designer’s knowledge (deGroot, 1995). Here we report on the methodology used to determine the vocabulary and provide a simple example of it being used to author feedback for students and its use in learning analytics.

3 METHODOLOGY

The c-book resources have been created to work both in the classroom and as online independent learning resources. When designing a c-book a designer has available many ‘widgets’. A widget is a distributed set of rich resources about mathematics. A c-book has access to set of these resources. The research study worked with four communities of interest that are participating in the EU project and creating different c-books based on different areas of mathematics.

To design the vocabulary required understanding the designers conceptual requirements and for them to make their tacit knowledge explicit. The principal being that if the designers had designed the feedback with concepts that made sense to them then it was more likely the results returned in the same context would be of value. An iterative approach has been used, using different design artefacts to share ideas about authoring learning analytics, using storyboards, knowledge elicitation templates of different artefacts that included online interviews, face-to-face workshops and partner meetings.

Role-play technique was used during an intensive face-to-face workshop. Two specific methods were adapted to facilitate knowledge capture from the designers. The first is the use of value creation stories, which draws on the work by Wenger (Wenger et al., 2008). These are usually used after engagement with a community tool or exchange to capture the value added experience to the users. The templates have been adapted as part of a knowledge engineering design process to capture key points by the designers e.g. using ‘AHA’ moments in conjunction with thinking aloud. ‘AHA’ moments are moments of sudden realization, inspiration, insight, recognition, or comprehension. This fits well within the context of creativity context used for designing the learning activities. Designers were being asked to ‘imagine’ how they would respond if the student was in the room with them. How and why they would respond to a particular context would form part of the model.

The second approach uses peer review process as a role-play activity. This provided the designers the opportunity to: (a) Explain their perspective of feedback given as a student, designer or learning analytics about a particular c-book, (b) Give details of the type of feedback that they felt would be beneficial depending what role they played and (c) Provide example concepts of creativity to author student feedback and identify creative mathematical thinking in students.

These two approaches meant that the designers did not focus on mathematical detail but on the learning experience for the potential students and what kind of authoring would help the students, as well as themselves.

4 MODEL AND KNOWLEDGE REPRESENTATION

It is possible to currently add feedback in the c-book design environment. The current feedback is specific to a particular mathematical concept and cannot be used across a variety of learning resources about pedagogical value and creativity.

Using learning about co-ordinates activity a simple authoring example of creative mathematical thinking in Figure 2 is provided. The student is given pathways to explore the learning resources. In this example if the student is struggling with the current task then the student is offered a different style of interaction to facilitate the elaboration process of thinking. The feedback needs to be created by the designer and authored as content for the purposes of elaboration. The content can then be annotated with these concepts and can later be explored in context with other data by the designer.

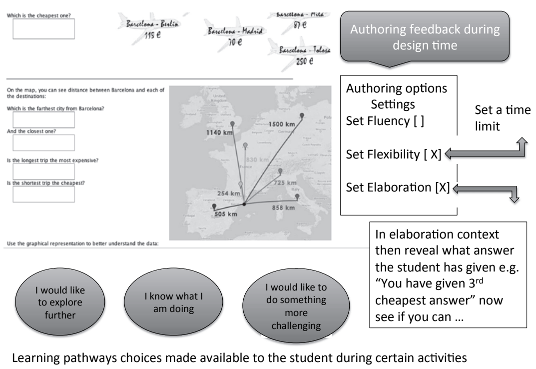

Figure 2: Authoring feedback example.

The flexibility concept here uses a simple timing constraint to challenge the student. A more elaborate activity could be created e.g. enabling the students to create their own travel challenges and the answers to these.

The concept of creative thinking through fluency is when engaging fluently and keeping pace with the task. The student can engage in elaboration or challenging activities at any point in the learning pathway.

4.1 Ontology Annotation Model

Using the above example we illustrate the use of the ontology model in the creation of learning pathways. We are using protégé to design and test out the vocabulary before integrating this into the learning analytics authoring of c-books platform. As a mediation vocabulary it needs to serve a number of requirements. Figure 2 indicates the authoring potential of the c-books. This is where the model functions to support designers to author feedback by extending a maths activity. The author/teacher is still designing but the ontology feature adds the annotations automatically when feedback is explicitly added. When a student uses the feedback or an implicit condition is reached (designed by the designer) then a feedback pathway is created.

There are two key points when the feedback is triggered and contributes explicitly to the learning pathway.

The first point is when the student actively decides to engage with an elaboration activity or a flexibility activity. The other is when the students perceived behaviour authored by the designer is recognised and feedback is automatically triggered.

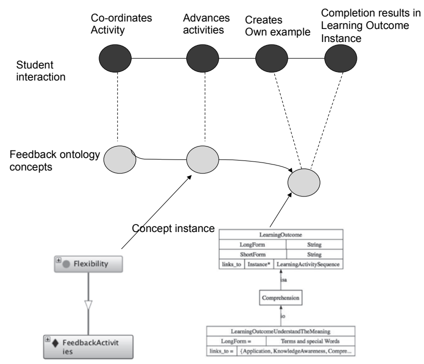

Figure 3: Example of annotated student's learning pathway.

In the example given about authoring, the student who encounters 'elaboration' feedback, in contrast to the students' who requests more challenging activities, will be engaged in further details and query about a specific question e.g. exploring the cheapest flight or ranking the flights further. These are key data points to be mapped to the common analytics that takes place. It is not expected that a student will engage only with one type of feedback so the learning pathway for any one student may have a number of different types of authored feedback. However, this permits a number of interesting explorations into the data about the students to be reflected on as the student's learning pathway is now annotated with these concepts (see figure 3). For example, more insight may be possible if when seeing the results of students who performed well in later tasks about coordinates, one can explore which feedback did they seem to benefit from. When misconceptions prevail, which feedback was used or not used. Did the results of the student's interactions match the expectations of the designer? The learning analytics tool can now use this knowledge to provide this feedback to the designers.

5 FINDINGS

Using one of the activities in the c-book called coordinates we illustrate the process used and a summary of the initial findings. The c-book unit 'Coordinates and points' targeting first-year secondary school students (12-13 years old), presents an introduction to the Cartesian coordinate system and the notion of ordered pairs. An objective of the c-book is to help students understand points on a graph. Firstly, students are asked to reason qualitatively about the meaning of points plotted on a graph. Secondly, a quantitative notion is introduced in order to establish connections between points and to get a preliminary notion of functions.

The students are encouraged to understand different representations and to interpret the knowledge that is presented. One of the challenges for students is to remember and understand the Cartesian representation (x,y) and the importance of order. Also, there is the visual representation of information and categorisation challenge.

General advice and guidance requirements about supporting the use of the activities emerged. The designers as students working on a 'c-book' that wasn't their design encountered challenges. In certain activities the recognition of correct or incorrect answers led to the designers articulating that feedback operates on several levels and this needs to be recognised and handled. For example at the c-book level, hinting to a student 'look at this other page in a c-book', another example at presenting the scores, results, activity used, and maybe expectations. Also, evaluating if students correctly use representations etc. This experience for the designers and knowledge engineers leads to requirements of the mathematical widgets capabilities in supporting such knowledge. While pivotal but for most technical designers an almost obvious requirement in designs of systems but difficult to articulate this requirement in such a complex system.

Reflective points for the designers emerged requiring the creation of student exploration space/ to work through an answer and not just gaming the system. Feedback trigger rules could be designed and further requirements/dependencies of widgets capabilities where considered (a) Registering attempts, time and determine what type of feedback to present based on this, (b) Use delayed feedback, so allow students to do what they want to do, to allow for 'gradual insight' and (c) After X attempts enable 'automatic' interoperability between widgets: show where points placed.

Classification of misconception and forming elaboration pathway for exploration with the student: (a) For example having a completely wrong set of coordinates is not the same as mixing up x and y coordinates, (b) Scaffold the feedback: provide different levels of feedback e.g. an example, a mode, an open question ("look at the x and y's more carefully") and (c) Exploration to deeper knowledge that supports pedagogical completeness and soundness e.g. After the graph there needs to be a question about the relationship.

In any activity a student can move between a state of being (a) over-challenged (e.g. stuck) (b) in flow or (c) under-challenged (e.g. because the activity is too easy). The learning pathways emerged identifying the students demonstrating creative thinking through elaboration, flexibility and fluency. This is a key observation and finding. For example, in the coordinates book the students are given a table to interact with and to plot co-ordinates. It is assumed to be prior knowledge. If this is not correct then maybe feedback referring to where this is explained and to explain what the student doesn't know. This is an elaboration process. At this point we see that the designers are now mapping 'an idea' of designing feedback to match the learner's possible 'creative' state of learning. Thus to enable the learning to move on if a student is in an elaborative learning state then the feedback to engage with the learner is designed to develop elaborative learning.

In another example c-book adaptivity was required to reveal hidden pages, revealed if the student is struggling or create an extension option for students who are finding this too easy. The feedback was designed with both elaborative and flexibility types of feedback to bridge knowledge gaps. The extension activities would be other pages of a c-book revealed under the right conditions.

This led to the designers thinking about self-reporting by student (for example opinion usefulness of tool) can be compared with actual user logs etc. This reflective log provides elements of 'value creation stories'. While this is a qualitative expression of knowledge the design of a quantitative led inquiry provides three points of data analytics that the designer can reflect on (a) the learning pathway (authored through the feedback process) taken by the student, (b) the actual data from the tasks completed and (c) the student's view of their progress.

Requirements emerged for feedback triggers. Also, feedback needs to be designed to pose questions rather than fixed answers. The questions form part of the feedback leading students through different learning pathways.

From the initial analysis of the data we define three of the concepts from a pedagogical perspective and learning pathway. These definitions may form a different focus from that of the creativity perspective:

Elaboration this we define as providing more detail about the current context and is seen as the 'easier' entry point into a problem space. This pathway is used when a student's conversation is frozen (Holmberg, 1983). Elaboration uses the current context and encourages the student to expand and investigate the problem space.

Fluency is the production of ideas, alternatives or solutions. It has been shown that the more ideas we produce, the more likely we are to find a useful idea or solution. Here when fluency is in action there is potential retention of previous concepts/knowledge that is to be applied to the problem space. Not only knowing what to use and draw-upon but also how to apply the knowledge to this context. This is when the learning pathway is going in the right direction/as planned by the designer.

Flexibility is especially important when logical methods fail to give satisfactory results. Thus a pathway that starts with elaboration may result in flexibility occurring and the student uses a novel (unexpected or not taught or a collection of usual techniques) to resolve the problem.

6 CONCLUSIONS

Both the design of the conceptual framework to capture the vocabulary and the use of it to contextualise learning pathways through feedback are novel. The added value of ontology driven education tools through the annotation process can add context to the artefacts, in this case c-books. What is challenging in creating AI and learning analytic solutions in this area is lack of methodology that identifies the boundaries of the knowledge representation otherwise the task is too complex. The complexity arises from the knowledge integration within systems that are intricate pieces of software dealing with large sets of structured and unstructured data. For example in this project there are complex mathematical widgets that perform multiple levels of computation supporting the design of learning activities. Thinking of the knowledge integration as a mediation task rather than exposing in depth software operations of the widgets provides a design of loose software coupling. This in software engineering is done through for example, APIs. However, the API level for many designers to use would require too much technical knowledge. An API definition is too fine grained and does not operate at the design level for authoring learning activities. However, enabling a knowledge integration of the widgets feedback capabilities is 'closer to' the right level for the designers. It requires 'extension' to the software of each widget's API but this is relatively minor at a technical level.

Another feature is the authoring of learning analytics. For example we chose one aspect of authoring, that of student feedback. Student feedback has a large body of knowledge and like creativity or the mathematical widgets we have to limit the degree of knowledge to what has meaning to the designers, what will add value to the process of design, use and reflection. We used the designers to guide this aspect. Expecting the designers to author everything would be tedious and no doubt stop the designers from focusing on their core task of creating c-books. It is important that the authoring process brings value in design as well as the use of the design and the analytics to follow.

We have benefitted from combining two methodologies of design: knowledge engineering and design-based method. For example knowledge representation looks for the explicit concepts 'for ontology commitment' and design-based methodology uses 'thinking aloud' and value creation stories to express concepts of importance.

Using a vocabulary that is 'subject matter agnostic' in education terms (not knowledge representation terms) and foster a space to reflect, such as creativity to author feedback may itself offer insights into the design process. Creativity concepts in this context may facilitate the design of more appropriate activities and feedback. The use of a digital mediation space illustrates the potential for designing explicit knowledge in less well defined domains. A key contribution to how to design ontologies for education and creativity by combining knowledge elicitation and design-based methods.

Finally, this design process was to support the authoring of learning analytics. Does the result of such a process provide insight for the designers? The evaluation of embedding the ontology and testing with designers the automated process is the next step. It will no doubt reveal more about designing a mediation vocabulary and the potential of the combined methodologies of design-based and knowledge representation to advance the scaling up and re-use of learning activities.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement N0610467 - project ”M C Squared”. This publication reflects only the author’s views and the EU is not liable for any use that may be made of the information contained therein.

REFERENCES

Bokhove, C., Jones, K., Charlton, P., Mavrikis, M. and Geraniou, E., (2014). Authoring your own creative, electronic book for mathematics: the MC-squared project. In, Keith Jones, Christian Bokhove, Geoffrey Howson and Lianghuo Fan (eds.). Proceedings of the International Conference on Mathematics Textbook Research and Development (ICMT-2014). Southampton, GB, University of Southampton, 547-552.

Charlton, P., Manolis, M, Katsifili. D., 2013. “The Potential of Leaning Analytics and Big data”, in Adriane, 2013,

Charlton P., Magoulas G., Laurillard, D., 2012. Enabling Creative Learning Design through Semantic Web Technologies, Journal of Technology, Pedagogy and Education July 2012.

deGroot, A. D., 1965 Thought and Choice in Chess. The Hague, the Netherlands: Mouton. 1969 Methodology: Foundations of Inference and Research in the Behavioral Sciences. New York and the Hague, the Netherlands: Mouton.

Holmberg, B. (1983). Guided didactic conversation in distance education. In D. Sewart, D. Keegan, and B. Holmberg (Eds.), Distance education: International perspectives (pp. 114-122). London: Croom Helm.

Jonassen, D. H., Thinking technology: Toward a constructivist design model, Educational Technology, 34(2), 34-37, 1994.

Karkalas, S., Bokhove, C., Charlton, P., & Mavrikis, M. (2015, June). Towards Configurable Learning Analytics for Constructionist Mathematical e-Books. In AIED (Vol. 2015).

LAK (2011) Learning Analytics and Knowledge, [1]http://solaresearch.org/

Laurillard, D., Charlton, P., Dimakopoulos, D., Ljubojevic, D., Magoulas, G., Masterman, E., Pujadas, R., Whitley, E.A., & Whittlestone, K. (2013) A constructionist learning environment for teachers to model learning designs. JCAL.

Leikin, R. (2009). Exploring mathematical creativity using multiple solution tasks. In R. Leikin, A. Berman, and B. Koichu (Eds.), Creativity in mathematics and the education of gifted students (pp. 129-145). Rotterdam, the Netherlands: Sense Publishers.

Merrill, M. D. Instructional Design Theory, Englewood Cliffs, NJ, Educational Technology Publication, 1994..

Mizoguchi, R., and Bourdeau, J Using ontological engineering to overcome common AI-ED problems. *International Journal of Artificial Intelligence in Education*, 11, 107-121, 2000.Paradigm of Instructional Theory, vol. II., Mahwah, NJ, Lawrence Erlbaum Associates, 1999.

Oliver, R., Harper, B., Hedberg, J., Wills, S. and Agostinho, S., Formalising the description of learning designs. In A. Goody, J. Herrington and M. Northcote (Eds), Quality conversations: Research and Development in Higher Education, vol. 25, Jamison, ACT, HERDSA, 2002.

Reigeluth, C. M.. What is Instructional-Design Theory and How Is It Changing? In C.M. Reigeluth (Ed), Instructional-Design Theories and Models: A New Paradigm of Instructional Theory, vol. II., Mahwah, NJ, Lawrence Erlbaum Associates, 1999.

Wenger Etienne, Trayner Beverly, de Laat Maarten (2008) Promoting and assessing value creation in communities and networks: a conceptual framework http://wenger-trayner.com/documents/Wenger_Trayner_DeLaat_Value_creation.pdf.

Ruthven, K. (2008). Mathematical technologies as a vehicle for intuition and experiment: A foundational theme of the International Commission on Mathematical Instruction, and a continuing preoccupation. International Journal for the History of Mathematics Education, 3(2), 91-102.

Silver, E. A. (1997). Fostering creativity through instruction rich in mathematical problem solving and problem posing. ZDM, 3, 75-80.