Frames: Active Examples for Technical Documents

ABSTRACT

In this paper, we propose the Frames method, which allows to generate frame-based user assistance interactions from content-structured representations of the underlying knowledge. These can be seen as joint generalizations of examples and practice problems often present in technical documents.

1. INTRODUCTION

Many aspects of modern life and work require special knowledge about the underlying processes and the laws that govern them. Traditionally, this knowledge is acquired by studying technical documents or via personal instruction. Knowledge acquisition via technical documents is very scalable, since documents can be nearly arbitrarily copied, thus they constitute important learning materials in informal learning situations. Unfortunately, technical documents are often not only hard to understand but the factual knowledge they impart are also difficult to apply to real-world situations. This limits their usefulness for the very goal they are written to achieve. The real-world examples often used in technical documents cannot fully solve this problem, since they are static and do not allow the user to explore the mapping of concepts between the learning objects and the example situation. Some learning materials and technical documents (usually tutorials) even use practice problems – a variant of real-world examples, which requires the reader to find this mapping – with the same problems.

To alleviate this shortcoming, we have developed the Frames method to generate interactive application scenarios from graph-structured representations of the knowledge to be conveyed. Frames is based on a cognitive practice often used in mathematics which views objects of interest in terms of already understood structures and make creative use of this new perspective. We adopt the term '**framing**' for the mathematical practice[1] since the term '**frame**' has been used e.g. in Communication Research as "*schemata of interpretation that enable individuals to locate, perceive, identify and label occurrences within their life space and the world at large.*" [Sno+86]; a frame is understood as a *scaffolding of concepts that influence the understanding of situations*. With the Frames method we adapt a technical realization of framing suggested in [KK09], and extend it to general (technical) domains and informal learning situations addressed by technical documents. In this account of framing knowledge is represented in a graph (which we interpret as a learnning object graphs) whose nodes are learning objects or descriptions of real-world situations and the edges are views (interpretations between learning objects and situations), which can act as framings.

The paper is organized as follows: In section 2, we analyze the issues restricting the usefulness of technical documents as informal learning materials. Taking yielding requirements into account, we present in section 3 the Frames method, together with an active exemplary practice problem and an even more active Serious Game use case to show off the potential of Frames. In the final section we summarize and give a prospect at further work.

2. READERS' ISSUES WITH TECHNICAL DOCUMENTS

If we consider all technical documents to be learning material in a broad sense, then an improvement has to take the point of view of the learners using them: the readers. So, what are readers' issues with technical documents? As this question aims very wide and thus too wide, we concentrate in this paper on the rather small, but characteristic sample of mathematical documents to answer the question. This sample is not only well-known for readers issues, those issues have recently been under close scientific scrutiny because there is a shortage of anticipated readers from a societal standpoint.

As all sciences and engineering disciplines use mathematics as its lingua franca, they also inherit basic mathematical

[1]For instance, mathematicians understand certain point sets in three-dimensional space by viewing them as zeroes of polynomials. Then they may derive insights about these point sets by studying the algebraic properties of polynomials: We are framing the point sets as algebraic varieties (sets of zeroes of polynomials). Other intuitive examples of framing in mathematics consist e.g. in equipping a differentiable manifold with a (differentiable) group operation (arriving at a Lie group), or interpreting a Boolean algebra as a field of sets via Stone's representation theorem. The practice of framing is so valuable, since it allows to transport insights between seemingly disparate fields. Indeed, in mathematics many of the most famous theorems earn their recognition *because* they establish profitable framings.

myths. We therefore base our approach on a preliminary analysis of common misperceptions about mathematics that are transferred to natural sciences and engineering. Hence, we will start with an overview of this analysis yielding a suggestive list of requirements to address the resp. issues.

i) **Math is difficult:** In [HH03] Halpern and Hakel point out that learning is influenced by both the students' and the instructors' epistemologies. Specifically for math they report that many college students complain that they 'cannot do math' and academic sciences, but "*when questioned about this belief, what most are really saying is that they think learning ought to be easy but, in these disciplines, it is hard*" [ibd]. One issue with this is that students are often not aware that there are different learning processes, particular explicit and implicit ones. The latter occur unconsciously and are only experienced as easy, once they have become automatic. However, for someone to become proficient in math, many hours of practice are required.

As a consequence, the *readers' motivation* need to be enhanced. To support readers' motivation (resulting in promoting automation) the new concept of gamification may come in handy. In particular, Serious Games — as games that engage users in activities other than pure entertainment according to Protopsaltis — can be used as vehicles of motivation (see e.g. [Kat11; FN09; SJ03]). Therefore , not only the time devoted will be increased considerably, moreover, the engagement will enhance the learning effect and thus result in assisting above automation.

The other issue raised by the Halpern and Hakel study is that

ii) **Math is difficult for *all* beginners:** In an educational physics setting White and Frederiksen asked students to rate a statement about their scientific aptitude: "*To be good at science, you need to have a kind of 'scientific mind'*" [ibd., p. 72]. 24% of all students attributed being good at science to an inborn ability–having a 'scientific mind'. In gender studies it is well-known that common gender stereotypes concerning scientific ability are objectively wrong, but if female subjects are pointed at these right before a test, they in turn perform bad as suggested by the stereotypes (see e.g. [Sch05]). In [FS10, p. xii] different 'cultural perspectives' between scientists and non-scientists are made out. Hegarty reports "*that spatial intelligence, which is supposedly the relevant one for scientific thinking, is not "just undersupported but underappreciated, undervalued, and therefore underinstructed" (p. 5)*" [Heg10, p. 266].

We conclude that the underlying complexity of technical documents has to be accepted at some point (in analogy to Tesler's "Conservation of complexity" law in Interaction Design), but that the real issue is *readers' attitude*. In order to motivate students to stay interested despite initial frustrations, the Frames method therefore draws on semantic technology to support scientific beginners with embedded, i.e., situation specific, scientific user assistance and traditional semantic services like 'definition lookup', 'guided tours' and metacognitive support.

iii) **Math is theoretical *and practical*:** The formalist view on mathematics (and an according positivist attitude towards science) — even though contradicted by Goedel's work — still is the dominant one not only in math education but also in Western culture (see e.g. [Enz99] or [KS01, 282ff.]). Computer scientists realized by now, that the rule-based algorithmic paradigm has to be replaced by an interaction one [Weg97]. Wegner argues for the replacement of pre-dominant rule-based algorithmic paradigm for computer problem solving by an interactive one. In particular, he points out that the "*goal of expressing semantics by syntax is replaced by the interactive goal of expressing semantics by multiple pragmatic modes of use*" [ibd., p. 88]. Shaffer and Kaput mention that "*the formalist position is that mathematical inquiry is, at heart, a 'game.' In this game, we define a set of symbols, a set of legal strings of symbols (axioms), and a set of rules for manipulating those symbols. The game is to determine what possible well-formed combinations of symbols (theorems) can be made from the starting set and the rules of combination. What is particularly important to note about this vision of mathematics is that the symbols don't necessarily refer to any specific external referent.*" [SK99, p. 13].

This game model is enabled by the mathematical practice of framing, where we take the term "practice" in the sense of Lave and Wenger, who introduced the concept of Communities of Practice [LW91] in 1991 as the context in which learning takes place and knowledge is produced. As already mentioned, with framing one views objects of interest in terms of already understood structures and make creative use of this new perspective. Thus, picking up or drawing on *scientific practices from within documents* is another improvement requirement to support the informal learning setting.

Moreover, this can be extended by supplying *external referents* to reflect the meaning and relevance behind math objects.[2] In particular, the integration of virtual objects that were created in the real world like pictures or short movies into documents will support the framing practice.

iv) **Math for digital natives:** The introduction of Digital Media had a tremendous impact on Western culture. The recognition that today's readers' needs for learning have changed, has not yet arrived e.g. in school curricula nor in the design of most technical documents. The well-known theories of Behaviorism, Cognitivism, and Constructivism provide an effect view of learning in

[1]Gamification is a fairly new word used to describe the process of incorporating game-like functionality into business processes in order to improve their effectiveness. The types of functionalities which are being incorporated within gamification include: scores, rewards and incentives, challenges, teamwork, leader boards and levels. Gamification is often aimed at building loyalty and motivation in relationships between suppliers and customers and employers and employees. Gamification seems to be developing increasing popularity in today's highly competitive environment.

[2]Our inspiration relies on examples like this one concerning Fibonacci numbers and the geometry in cones: `http://www.youtube.com/watch?v=ahXIMUkSXX0&feature=youtu.be&noredirect=1`

different environments and under different conditions, however, when learning moves into informal, networked, technology-enabled environments, these theories fall short.

Therefore, readers should be considered *prosumers* (in the Web2.0 fashion), that is, they should be enabled to generate their own digital content, relate it with already existing concepts in technical documents, and share it with others.

v) **Math is everywhere:** A general rule of thumb declares that an instructor should provide learners with examples of concepts, the more the better as the transfer deepens understanding (see e.g. [HH05; New89]). This is especially effective for math, as examples can not only be selected from different academic disciplines but also from many applied and abstract situations, see e.g. [FS10].

We conclude that it would be a great advantage for readers if they could relate concepts in technical documents to applied or abstract situations. This *transfer* could be extended to transdisciplinary transfer.

vi) **Math is social:** It is well-known that mathematicians and their professional practices are hard to study (see e.g. [KJ11; KK06], very few have even tried — a notable exception being the sociologist HEINTZ in [Hei00]. To her own amazement she found out that there are indeed important, *social* practices as in every other scientific discipline.

Thus, the building of *communities of readers* is another improvement goal, especially since

> "*People don't learn to become [... mathematicians] by memorizing formulas; rather it's the implicit practices that matter most. Indeed, knowing only the explicit, mouthing the formulas, is exactly what gives an outsider away. Insiders know more. By coming to inhabit the relevant community, they get to know not just the 'standard' answers, but the real questions, sensibilities, and aesthetics, and why they matter.*" [Bro05]

To summarize, the following issues should be adressed to improve technical documents: *i)* readers' motivation, *ii)* readers' attitude esp. overcoming initial frustrations, *iii)* scientific practices available from within documents and relating external referents to technical concepts, *iv)* readers' context/self-expectation as prosumers, *v)* occasions for knowledge transfer even possibly transdisciplinary, and *vi)* readers as social beings.

3. TOWARDS ACTIVE TECHNICAL DOCUMENTS

The issues identified above come in two categories: Firstly: *Issues with Motivation*: *ii)* and *i)*. Even though these are important in informal learning situations in general, they are secondary to our endeavor of improving technical documents. Providing help with understanding and application (see *iii)*) will help study motivation intrinsically; further motivation (especially for young readers) can be provided by embedding the Frames method into Serious Games environments. Secondly: *Barriers to Understanding.* Here we propose to use semantic technologies to assist beginners in math learning (*ii)*, *i)*), and math understanding with explicit references between theory and real world (*iii)*) and transdisciplinary bridges (*v)*). Concretely, we propose to extend technical documents – or serious games – with embedded, interactive semantic services based on semantic annotations in the documents themselves and associated learnning object graphs (see below).

3.1 The Frames Method

Currently, most knowledge in technical documents is presented informally, i.e., by physically arranging symbols on paper or a computer screen, with human beings interpreting the semantics of the physical layout. The main contribution of today's intelligent information technologies is to move from 'pen-and-paper-math' to a situation where knowledge is stored on computers as instructions for physical layout of text and symbols (written, e.g., in LaTeX or Presentation MathML [MML310], OpenMath [Bus+04], and OMDoc [Koh06]. The 'intelligence' of the computer resides in semantic technology, a branch of the field of Artificial Intelligence (AI). Semantic technologies are technologies that process semantic data, i.e., ordinary data that are extended by explicitly marking up the objects involved and their relations among each other, and which act on these sensibly through inference. They are knowledge management tools for mastering information complexity.

Formal representations of mathematics are needed for the application of semantic technology. The creation of these and languages and tools that support stepwise (= informal) formalization of unstructured natural language into formal representations are for instance supported by MathDox [CCB06], MathLang [KWZ08], or our own OMDoc [Koh06]. An integrated authoring, interaction, and information access workflow for OMDoc has been investigated under the heading of semantic publishing and has been implemented in the Planetary System [Koh+11]. In this, OMDoc is written in sTeX, a semantically enhanced version of LaTeX (see [Koh08; KKL10; JK10]) presented in a user-adaptive fashion in the Web-standard format XHTML5 (for documents with math and diagrams), which have been made interactive via embedded JavaScript that allows access to the content representations "behind the generated documents". As the OMDoc representations support the specification of logical, document, and even user context (see [KK08] for details), the format is ideal for marking up and formalizing re-usable learning objects. The ActiveMath system [Mel+01; MHS06] is an earlier implementation of the same approach and has been in wide use as an adaptive, personalized eLearning system for technical subjects in the European arena over the last decade. However, it is based on an earlier version of OMDoc, therefore the level of semantic services are below the level we need for Frames. Note that even though the semantic publishing workflow is based on a different knowledge representation approach than the Semantic Web, it is well-integrated with the Semantic Web via RDFa [Adi+08] annotations in the XHTML5 documents (see [Koh16; LK09; KKL10]). In particular, open content available in RDF triple stores can be reused in technical documents.

We integrate the knowledge representation approach and knowledge management systems into a specific knowledge graph approach — which we will call the "**Learning Object Graphs**" (LOG) approach. Here, learning objects are spec-

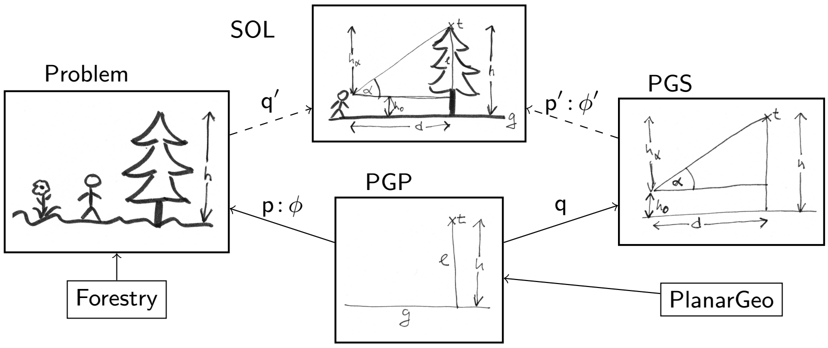


Figure 1: Framing for Problem Solving

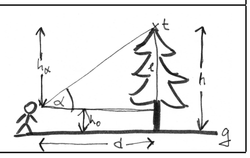
ified in "**theories**"[3], which are connected by "**theory morphisms**"[4], which encode mathematically well-understood and machine-actionable relations the objects specified in the theories they connect. There are various kinds of theory morphisms in LOGs:

1. "**inclusions**" that act as inheritance relations in an "object oriented" approach to knowledge representation. This allows to reuse the properties stated in the theories for multiple configurations of objects and thus achieve a modular and structured representation of the knowledge underlying the learning objects.
2. "**views**"[5] that allow to view a learning or problem as one that is already understood.
   Concretely, we *model the framing practice* by defining a **framing** to be the establishment (creating or choosing) of a theory morphism from a source theory (the **framing theory**) into the theory representing the problem (the **framed theory**). The theory morphism itself is called a **frame**. In situations where there is a unique morphism from a theory S to T, we will also say that S is a frame for T in a slight abuse of terminology. But note that in many situations we naturally have more than one morphism between two theories.
   This technique of framing via LOG views is our notion for the analogical transfer of mathematical solutions to applications.

The LOG approach has a well-studied theory [RK13] that has been used for knowledge management systems in mathematics, the hard sciences [KK09; Koh+11; Aut+11] and computer-supported education [KK08].

3.2 An Active Example: Framing a Simple Word Problem

To be more concrete in our usage of frames we present a very short and tentative sketch of a potential application (taken from [KK09]). We base it on a problem often found in the form of a word problem in high-school trigonometry lessons or as a basis for real-world 'applied geometry' projects:

Problem	Solution
How can you measure the height of a tree you cannot climb, when you only have a protractor and a tape measure at hand.	

The standard solution is to assume that the tree in question stands on flat ground, to mark the tree at eye height and to use the protractor for sighting the top of the tree and the mark to determine the angle α between the sightings. The tape measure can be used to determine the eye height (h_0) and the distance d between sighting point and the center of the tree. Then the height h of the tree is $h = h_0 + h_\alpha = h_0 + d\tan(\alpha)$ according to the sketch on the right.

Even in this simple situation, framing is complex; consider what happens in the solution process. The first step is to realize that certain concrete properties of the problem do not matter, in this case the shape of the tree, its color, and indeed that it is a tree at all; so in a first framing step, we map the problem to a simpler one of determining the length of a mathematical line segment without directly measuring it. The second step in solving the problem is to carefully add further objects to the problem (e.g. the mark and the sighting point) so that a solution can be found. And in a third step, the solution is mapped back to the original problem and verified there.

A part of the involved LOG is shown in Figure 1. The boxes represent theories and the arrows theory morphisms. The theory Problem on the left contains a description of the problem at hand (and inherits concepts from a theory forestry which we do not expand on here) and a theory PGP which we have chosen to contain the geometric essentials of the problem (a horizontal base line with an orthogonal line segment of height h). On the right we have a theory PGS that extends theory PGP with the geometric construction in the mathematical solution $h = h_0 + d \cdot \sin(\alpha)$. We call the theories PGP and PGS together with the inclusion morphism q a **problem/solution pair**.

The key to solving the word problem is to identify a problem/solution pair such that the problem specification matches the scene. In the theory graph in Figure 1, this can be expressed by exhibiting a view p with symbol mapping ϕ which identifies e.g. the (center of the) tree with the line segment l and the ground with the straight line g in configuration PGP. Our meta-theory of theories now guarantees a

[3] technically: sets of concepts (called symbols), model assumptions (called axioms)

[4] technically: symbol mappings, so that all translated axioms are "true" (= provable) in the target theory

[5] technically, views connect theories that do not inherit from each other, to establish a view, we have to prove that the axioms of the source theory translated to the target theory hold in the target theory.

theory SOL (as the categorial pushout of the morphisms p and q; see [RK13] for details), which suitably merges material from Problem and PGS and establishes the height h of the tree to be $h = h_0 + d \cdot \sin(\alpha)$ (this is contributed by PGS), where h_0 is the eye height of the measuring person, α is the angle measured by the protractor and d is the distance of the person to the tree measured by the tape (these three identifications are contributed by the matching morphism $\mathsf{p}' : \phi'$, which extends the matching morphism $\mathsf{p} : \phi$). We call these two theory morphisms **framing morphisms**.

3.3 An Even More Active Example: A Use Case for a Serious Game

Let us envision that Clara and David, both tenth grade students, have to do a Frames Serious Games project on this word problem. Their idea is to design a two-dimensional scenario, in which a person needs to jump on top of the tree to reach a treasure lying behind. First, they start gathering pictures of trees in the local neighborhood and of themselves, so that they can use those as game objects. There already is a set of math objects wrt. to a "height of a tree" problem present in the game repository. When they try to align those with the tree pictures they gathered, they realize that the semantic game engine does not let them use all tree pictures. Actually, only the ones which depict almost-straight trees are admissible. They realize quickly the underlying reason, namely that the whole problem scenario is based on the right angle between ground and tree. Clara likes flowers, so she adds a nice bunch of flowers and a giant one between the virtual character (picture of herself) and the chosen tree. The giant one she construes as subproblem in the game: players have to cut it before the mathematical scenario can be applied. David adds another subproblem by putting a middle-sized straight tree in-between, so that players need to first solve the same problem for the smaller tree, in order to jump on its top. Both have aligned math objects like straight lines and angles with their personal game objects along the way. Finally, they decide on the success criterion for jumping based on the trigonometric theorem that the tangent of an angle in a Pythagorean triangle is the fraction of the opposite and adjacent side lengths. Their friends are called to test the game, give feedback and even extend it.

Figure 2 depicts the scenario: On the one hand, we have three levels to the learning situation: *1)* "Game World" with game objects: a game-specific, possibly user-generated (description of the) problem situation on the right, *1)* "Theory World" with content: the (mathematical representation of the) geometry to be applied on the left, *1)* "Real World" with copies: objects created by a user e.g. with her smart phone (the anchor). On the other hand we have two bridges: *a)* the representation of the real world in the game world, and *a)* the alignment between the game elements and the mathematical configuration (the framing). Note that the arrow between the theory world and the real world is only established in the mind of the game author or player, as it represents the recognition of the meaning of the mathematical theory in the real world. Note moreover, that in this scenario all the levels and bridges can be mixed and matched within a game, the learning of the third bridge ("meaning") is implicit.

3.4 Transdisciplinary Bridges

Note that the diagram in Figure 2 can directly be extended

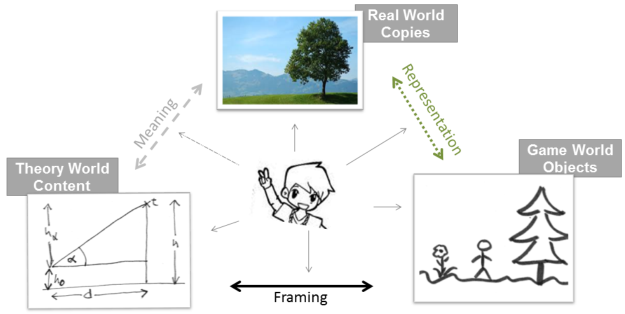


Figure 2: Bridges between Reality, Game Objects, and Theory Content

to a transdisciplinary setting by framing a learning object in multiple application scenarios via frame morphisms; see Figure 3 involving trees of various kinds. Note hover, that the salient features picked out by the framing morphisms may be different, this poses constraints on the composition of frame morphisms.

4. CONCLUSION AND FUTURE WORK

We have presented the Frames method for generating interactive application scenarios from learnning object graphs based on explicit representations of framings, i.e., interpretations that allow new objects (or structures in application scenarios) in terms of already-known ones (problem/solution pairs). We have analyzed shortcomings of technical documents, using mathematical aspects as a test tube domain. This is well-suited for such an analysis, since mathematical knowledge contributes a major portion to the understanding and application problems of technical documents and mathematical knowledge is usually well-structured and rather explicitly represented. We have exemplified the Frames method by embedding it into a practice problem and a serious games scenario.

The Frames method is already partially implemented: The Learning Object Graphs can be written in sTeX and managed in the Planetary System [Koh+11]. If we restrict ourselves to fully formal representations of the underlying knowledge, we can construct the top nodes of the diamonds as in Figure 1 automatically via the MMT System [MMT; RK13]. These represent the applied problem solution (and thus the worked example).

For a full future implementation of the Frames method, the framing algorithms would have to be embedded into actual technical documents (and thus extended to informal content). For real-world application scenarios have to represent the respective scenes as special "learning objects" that represent semantically salient objects of the scenes and their relations among each other in the learnning object graphs graphs. Observe that the underlying mathematics and logic is the common language of all technical domains, and thus the existing framing algorithms are essentially sufficient, except that we need to be able to compute values (by partial, symbolic evaluation) induced by the views to interface objects (and thus scenes).

Given that views into interface theories are central representations in the Frames method, we need ways for readers to interact with them, especially in a serious games scenario:

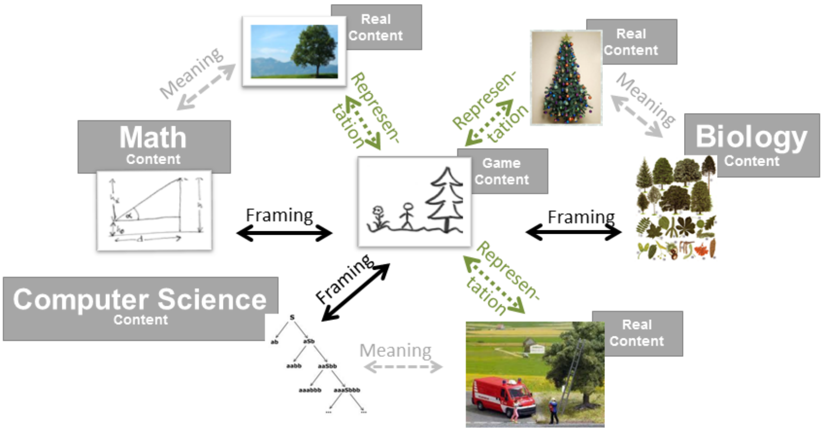


Figure 3: Bridges between Disciplines for Framing

a) Readers and players need to be able to create, inspect, and adapt views from inside the game scene, in ways that don't break the current metaphors. *b)* Learning object and game content providers need to make use of the inherent modularity of learnning object graphs views for reuse. For *a)*, we plan to develop direct-manipulation interfaces that rely on highlighting of interface objects for inspection and drag/drop interactions for creating/ modifying views. For *b)* we will develop naming/referencing schemes for views that facilitate reuse.

Acknowledgements

The authors gratefully acknowledge inspiring discussions with Lucia Pannese that helped refine some of the ideas presented in this paper. Work on this paper was supported by the German Research Council (DFG) under grant KO 2428/10-1.

References

[Adi+08] Ben Adida et al. *RDFa in XHTML: Syntax and Processing*. W3C Recommendation. World Wide Web Consortium (W3C), Oct. 2008.

[Aut+11] Serge Autexier et al. "Workflows for the Management of Change in Science, Technologies, Engineering and Mathematics". In: *Intelligent Computer Mathematics*. Ed. by James Davenport et al. LNAI 6824. Springer Verlag, 2011, pp. 164–179.

[Bro05] John Seely Brown. *Learning in the Digital Age*. Available at `http://net.educause.edu/ir/library/pdf/FFPIU015.pdf`. Accessed on 2011-05-11. 2005.

[Bus+04] Stephen Buswell et al. *The Open Math Standard, Version 2.0*. Tech. rep. The OpenMath Society, 2004.

[Car+09] Jacques Carette et al., eds. *MKM/Calculemus Proceedings*. LNAI 5625. Springer Verlag, July 2009.

[CCB06] A. M. Cohen, H. Cuypers, and E. Reinaldo Barreiro. "MathDox: Mathematical Documents on the Web". In: *OMDoc – An open markup format for mathematical documents [Version 1.2]*. LNAI 4180. Springer Verlag, Aug. 2006. Chap. 26.7, pp. 278–282.

[Enz99] Hans Magnus Enzensberger. *Drawbridge Up: Mathematics — A Cultural Anathema*. Nadick, MA: A K Peters, 1999.

[FN09] S. de Freitas and T. Neumann. "The use of 'exploratory learning' for supporting immersive learning in virtual environments". In: *Computer and Education* 52.2 (2009), pp. 343–352.

[FS10] Marilyn Fenichel and Heidi A. Schweingruber. *Surrounded by Science: Learning Science in InformalEnvironments*. National Science Council, 2010.

[Heg10] Mary Hegarty. "Components of Spatial Intelligence". In: *The Psychology of Learning and Motivation*. Ed. by B.H. Ross. Vol. 52. San Diego, CA: Academic Press, 2010. Chap. 7, pp. 266–297.

[Hei00] Bettina Heintz. *Die Innenwelt der Mathematik. Zur Kultur und Praxis einer beweisenden Disziplin*. Wien: Springer Verlag, 2000.

[HH03] Diane F. Halpern and Milton Hakel. "Applying the Science of Learning". In: *Change* (2003), pp. 36–41.

[HH05] Diane F. Halpern and Milton Hakel. "How far can transfer go? Making transfer happen across physical, temporal, and conceptual space". In: *Transfer of learning: From a modern multidisciplinary perspective* (2005), pp. 357–370.

[JK10] Constantin Jucovschi and Michael Kohlhase. "sTeX-IDE: An Integrated Development Environment for sTeX Collections". In: *Intelligent Computer Mathematics*. Ed. by Serge Autexier et al. LNAI 6167. Springer Verlag, 2010, pp. 336–344. arXiv: `1005.5489v1 [cs.OH]`.

[Kat11] Pamela Machiko Kato. “Using serious games to improve communication: talking about a revolution”. In: *Proceedings of the 29th ACM international conference on Design of communication*. SIGDOC ’11. Pisa, Italy: ACM, 2011, pp. 261–262. DOI: 10.1145/2038476.2038527.

[KJ11] Andrea Kohlhase and Constantin Jucovschi. “planMP: Collecting Mathematical Practices for MKM”. In: *Work-in-Progress Proceedings of CICM 2011*. University of Trento, 2011.

[KK06] Andrea Kohlhase and Michael Kohlhase. “Communities of Practice in MKM: An Extensional Model”. In: *Mathematical Knowledge Management (MKM)*. Ed. by Jon Borwein and William M. Farmer. LNAI 4108. Springer Verlag, 2006, pp. 179–193.

[KK08] Andrea Kohlhase and Michael Kohlhase. “Semantic Knowledge Management for Education”. In: *Proceedings of the IEEE; Special Issue on Educational Technology* 96.6 (June 2008), pp. 970–989.

[KK09] Andrea Kohlhase and Michael Kohlhase. “Spreadsheet Interaction with Frames: Exploring a Mathematical Practice”. In: *MKM/Calculemus Proceedings*. Ed. by Jacques Carette et al. LNAI 5625. Springer Verlag, July 2009, pp. 341–356.

[KKL10] Andrea Kohlhase, Michael Kohlhase, and Christoph Lange. “sTeX – A System for Flexible Formalization of Linked Data”. In: *Proceedings of the 6th International Conference on Semantic Systems (I-Semantics) and the 5th International Conference on Pragmatic Web*. Ed. by Adrian Paschke et al. ACM, 2010. DOI: 10.1145/1839707.1839712. arXiv: 1006.4474v1 [cs.SE].

[Koh06] Michael Kohlhase. *OMDoc – An open markup format for mathematical documents [Version 1.2]*. LNAI 4180. Springer Verlag, Aug. 2006.

[Koh08] Michael Kohlhase. “Using LaTeX as a Semantic Markup Format”. In: *Mathematics in Computer Science* 2.2 (2008), pp. 279–304.

[Koh+11] Michael Kohlhase et al. “The Planetary System: Web 3.0 & Active Documents for STEM”. In: *Procedia Computer Science* 4 (2011): *Special issue: Proceedings of the International Conference on Computational Science (ICCS)*. Ed. by Mitsuhisa Sato et al. Finalist at the Executable Paper Grand Challenge, pp. 598–607. DOI: 10.1016/j.procs.2011.04.063.

[Koh16] Michael Kohlhase. “An Open Markup Format for Mathematical Documents OMDoc [Version 1.3]”. Draft Specification. 2016. URL: https://github.com/OMDoc/OMDoc1.3/spec/main.pdf.

[KS01] James Kaput and David Shaffer. “On the Developemtn of Human Representational Competence from an Evolutionary Point of View. From Episodic To Virtual Culture”. In: *Symbolizing, Modeling and Tool Use in Mathematics Education*. Ed. by K. Gravemeijer et al. Netherlands: Kluwer Academic Publishers, 2001, pp. 269–286.

[KWZ08] Fairouz Kamareddine, J. B. Wells, and Christoph Zengler. “Computerising Mathematical Text with MathLang”. In: *Electron. Notes Theor. Comput. Sci.* 205 (2008), pp. 5–30. DOI: 10.1016/j.entcs.2008.03.063.

[LK09] Christoph Lange and Michael Kohlhase. “A Mathematical Approach to Ontology Authoring and Documentation”. In: *MKM/Calculemus Proceedings*. Ed. by Jacques Carette et al. LNAI 5625. Springer Verlag, July 2009, pp. 389–404.

[LW91] Jean Lave and Etienne Wenger. *Situated Learning: Legitimate Peripheral Participation (Learning in Doing: Social, Cognitive and Computational Perspectives S.)* Cambridge University Press, 1991.

[Mel+01] E. Melis et al. “ActiveMath System Description”. In: *Artificial Intelligence in Education*. Ed. by Johanna D. Moore, Carol Luckhard Redfield, and W. Lewis Johnson. Vol. 68. Frontiers in Artificial Intelligence and Applications. IOS Press, 2001, pp. 580–582.

[MHS06] Erica Melis, Jeff Haywood, and Tim Smith. “LeActiveMath”. In: *Innovative Approaches for Learning and Knowledge Sharing*. Ed. by Wolfgang Nejdl and Klaus Tochtermann. LNCS 4227. Springer Verlag, 2006, pp. 660–666.

[MML310] Ron Ausbrooks et al. *Mathematical Markup Language (MathML) Version 3.0*. Ed. by David Carlisle, Patrick Ion, and Robert Miner. 2010. URL: http://www.w3.org/TR/MathML3.

[MMT] Florian Rabe. *The MMT System*. URL: https://uniformal.github.io/doc/ (visited on 07/16/2014).

[New89] Nora S. Newcombe. “Biology Is to Medicine as Psychology Is to Education: True or False?” In: *Applying the Science of Learning to University Teaching and Beyond, New Directions for Teaching and Learning*. Ed. by D. F. Halpern and M. D. Hakel. San Fransisco, CA: Jossey-Bass, 1989, pp. 9–18.

[RK13] Florian Rabe and Michael Kohlhase. “A Scalable Module System”. In: *Information & Computation* 0.230 (2013), pp. 1–54.

[Sch05] Ralph Erich Schmidt. “Die Mühen der Frauen mit der Mathematik: Negative Vorurteile beeinträchtigen die Leistungsfähigkeit”. In: *Neue Zürcher Zeitung* 69 (Mar. 2005), pp. 65–66.

[SJ03] Kurt Squire and H. Jenkins. “Harnessing the power of games in education”. In: *Insight* (2003), pp. 5–33.

[SK99] David Williamson Shaffer and James J. Kaput. “Mathematics and virtual culture: An evolutionary perspective on technology and mathematics education”. In: *Educational Studies in Mathematics*. 1999, pp. 97–119.

[Sno+86] David A. Snow et al. “Frame alignment processes, micromobilization, and movement participation”. In: *American Sociological Review* 51.4 (1986), pp. 464–481.

[Weg97] Peter Wegner. "Why interaction is more powerful than algorithms". In: *Commun. ACM* 40.5 (1997), pp. 80–91. DOI: `http://doi.acm.org/10.1145/253769.253801`.