Interoperable Interactive Geometry for Europe*

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Abstract

The Intergeo project is driven by a consortium of commercial, semi-commercial and open-source software producers as well as mathematics educators from all over Europe. The primary goal is to make mathematics driven by interactive resources more accessible to all teachers and learners, by facilitating the search, use and quality assurance of them. In this article I will highlight the main obstacles we faced and how we approached them and give an outlook on the future of interactive geometry and the project. Furthermore, I will raise some didactical and research questions that should be answered if we really want to integrate computer-based teaching, learning and assessment into our curricula.

This article is a written version of the keynote held at the CADGME 2010 conference in Hluboká, Czech Republic. It does not, cannot and should not contain references for all claims made, but rather summarize the Intergeo project and serve as an introduction to the various publications of the project that are available on its website `http://i2geo.net`*. We refer to those for a much deeper description of each of the issues raised, as well as proper references to existing work.*

1 Prelude

Technology use in mathematics lessons is a necessary component of modern teaching – at least it seems so, as curricula all over Europe start to stress the importance of technology and media use. However, often the use of computers is not justified through didactical reasons from a mathematics education perspective, but rather by sociological, economic, political, or even irrational reasons. Computers are used because parents think their children might be left behind, or because teachers fear that their teaching cannot match the motivational character of computer games. Media is used to make up for a shorter attention-span of the students, or because it is less work to prepare a lesson by opening a tin-canned activity.

*The Intergeo project is co-funded by the European Union, through the eContentplus programme, see `http://ec.europa.eu/econtentplus`.

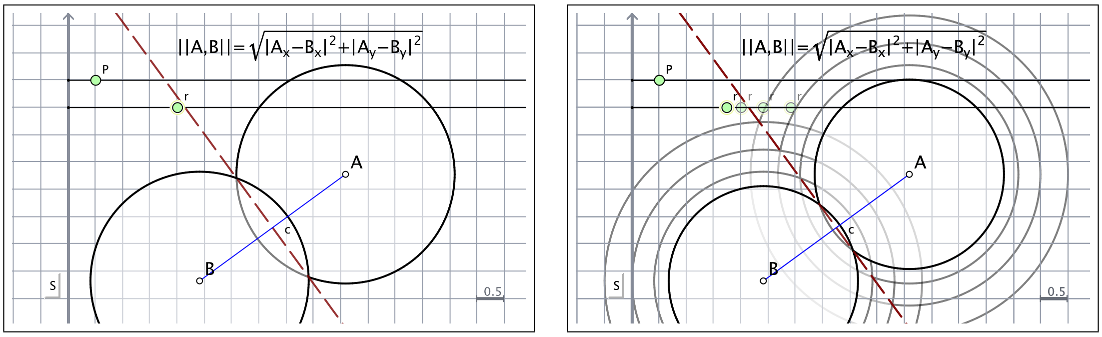

Figure 1: Finding the bisector of two points by varying the radius. Left: The bisector is the connecting line of the intersections of two equal-radius circles. Right: The bisector is the locus of all the intersections of pairs of equal-radius circles.

This is a justification for reluctant teachers to minimize their technology use. Also, it is difficult to reply to the claim that those who should teach now learned their mathematics without a computer, so it is definitely possible to understand all that is needed just with pencil and paper, q.e.d.

Unless we can convince teachers that using computers or handheld devices in mathematics teaching does improve the learning of mathematics, the understanding of concepts, the change of beliefs, the connection of knowledge, it is futile to help them to integrate technology in the classroom.

Of course, there is a lot of research about the effectiveness of computer tools for teaching [5], but it may be asking for too much that teachers actually read these publications. In addition, there is also research that shows that there is no or even a contrary effect. The common line of argumentation of techno-enthusiasts is that there is a need for a different culture of exercises. This argumentation is usually used when the focus is on mathematical competence that is showing in *processes* instead of *products*, but it is even more true (if truth could be compared) for exercises that just *make no sense* when a computer is available, and activities are possible that *cannot be done* without a computer.

We are not talking about magic devices like the Dynabook of Alan Kay [9], but when we want to reach better teaching through technology use we have to accept that the new tools must be used differently than the traditional ones.

A striking example[1] is the possibility to move[2] from static and isolated observations to dynamic and holistic ones. A well-known elementary construction is finding the bisector of two points using the intersection of two circles of equal radii (Fig. 1, left). The bisecting line can be generated by varying the radius in the same way for both circles (Fig. 1, right). Here already we develop a dynamic view on the situation by creating the bisector using a variation of the radius.

It is a non-trivial fact that the object created as the locus of the intersection of two circles is a line, and in fact this is only true for the usual norm used, the Euclidean norm $||x, y||_2 = \sqrt{x^2 + y^2}$. For

[1]One of the reviewers remarked that the example might be counter-effective for reluctant teachers, as they are scared away by such a mathematical treatment. This is true, but the example is directed at mathematicians and teachers who are proficient in mathematics and do not see a reason to use the computer at all. In fact, the last generation of mathematics teachers was able to learn maths without a computer, so they might argue that they don't need a computer to teach it.

[2]pun intended

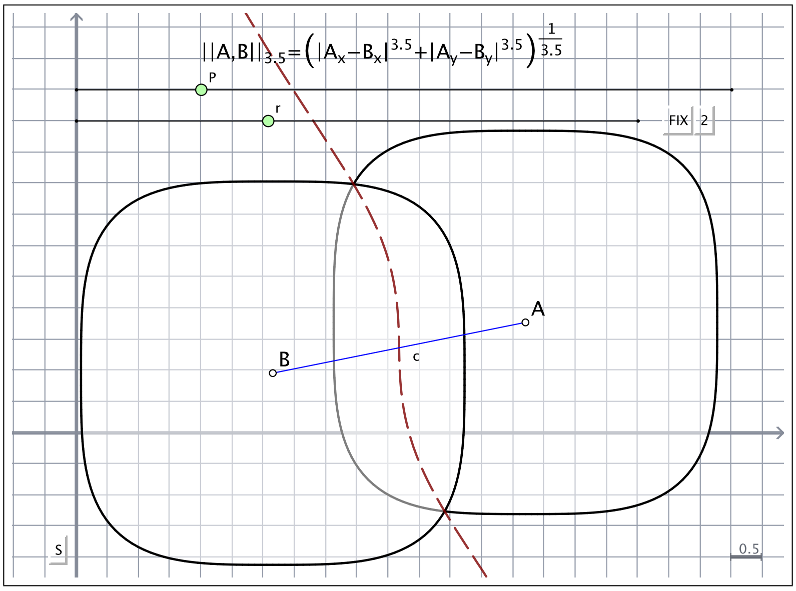

Figure 2: The bisector of A and B for the $L_{3.5}$-norm

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other definitions of "distance," say, the L_p-norm that is defined by

$$||x, y||_p = \sqrt[p]{x^p + y^p}$$

this locus will almost never be a straight line, as seen in Fig. 2. Here we do have a first small research problem for students (and teacher students): *In which cases, for which p or positions of A and B, is the locus a straight line? Classify them!*

Back to the Euclidean norm, i.e. $p = 2$: Working with bisecting lines we immediately arrive at one of the typical questions of high school geometry: Why do the bisectors of the three sides of a triangle meet in a point? There are many proofs using various techniques, for example based on the congruency of the three pairs of triangles created by subdividing the starting triangle with the point of intersection of two of the three bisectors. This proof is no longer possible if we change the underlying distance measure, as we need proper triangles with straight edges for the congruency argument. Still – the theorem is also true for other norms! The three bisectors in any norm of a triangle meet in point, no matter how serpentine they will be (Fig. 3).

It is only with the help of the computer that this theorem can be explored like its straight version, verifying it for many cases and thus raising the urge to prove it. The construction of a bisecting line in any other norm than the Euclidean one is too tedious to be done repeatedly by hand. The general proof, however, is amazingly easy, does not use congruency and just uses the transitivity of equality: The bisector b_{AB} of A and B is the locus of points of equal distance to A and B. Analogous statements hold for the bisectors b_{AC} and b_{CB}. A point of intersection of b_{AB} and b_{AC} thus has the same distance to B resp. C as it has to A, which in turn means that B and C have the same distance to it. Consequently, the point also lies on b_{BC}, q.e.d. The computer helps us to discover the mathematical essence of this rather classical theorem.

We have seen that the Computer is not a tool that just frees the student from routine tasks and

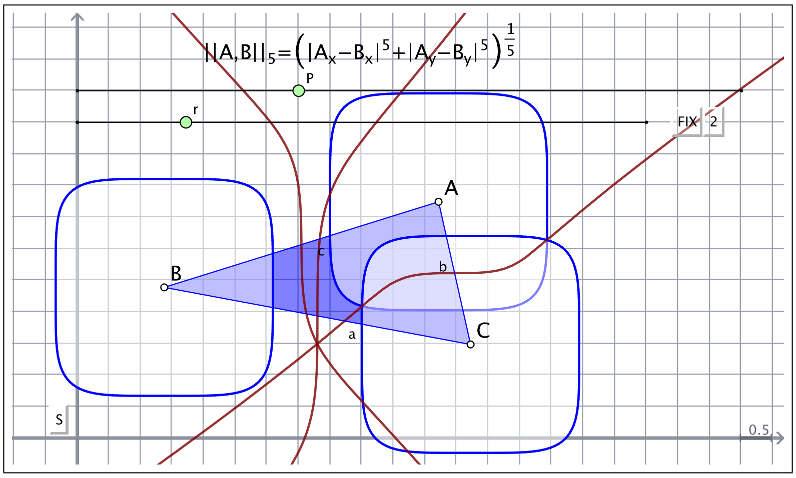

Figure 3: The angle bisector theorem in L_5 norm. Additionally, L_5-circles of same radius around A, B, and C are shown.

repeated or overly complex calculations. It offers a whole new view on mathematics, in particular geometry, and allows for new approaches to traditional problems. Students (and teachers) can gain deeper insight into the connections between different topics and techniques in mathematics. Thus, the sensible use of the computer is indispensable in responsible teaching. It is not just a tool to replace tedious work, but a method to understand better. We are following here the tradition of Felix Klein, who stresses the importance of application, but also the importance of comprehension.[3].

Intergeo should be a way to obtain the necessary content for such a sensible use. In this article we will describe how the project attacked the three main barriers of successful distribution of interactive geometry content: (1) The lack of a suitable search tool, (2) The software-originated problems of interoperability, and (3) The lack of quality metadata for classroom-tested examples.

2 Find — Google is Broken For Us

It is a matter of fact that there are thousands of great interactive geometry "resources," i.e. constructions, exercises, animations, illustrations, simulations, visualizations, . . . available on the Internet. They are scattered on individual home pages (for example at [28, 20, 13, 29], just to name a few of the thousands on the net) or available in collections of projects or institutions. The collections are either homogeneous due to editorial work [22, 3] or heterogenous due to a wiki-like approach [8], or somewhere in between [17, 24].

It is impossible to know all these sources — the examples above are only few of many — and a

[3]With respect to planimetric construction exercises Klein emphasizes that they are important for applying the acquired skills in geometry, but that they also bear the danger to become just a useless drill in an over-formalized setting: *Die Art jedoch, die darauf hinauskommt, daß sich der Schüler nur eine gewisse Rutine erwirbt, — ich meine das Verfahren, daß auf den verschiedenen Stufen wochenlang Dreiecke aus irgendwelchen fernliegenden Bestimmungsstücken theoretisch konstruiert werden — das muß uns doch als verfehlt erscheinen. Eine solche Behandlung dieser Aufgaben wäre nur von dem Standpunkt einer einseitig formalistischen Ausbildung zu rechtfertigen, und den können wir heute unmöglich gelten lassen.*[10]

teacher cannot check all sites and collections for the availability of a suitable resource in her everyday teaching. With the availability of search engines like Google or Bing it is no longer necessary to really know the best places in the Internet (there have been printed books with the TOP 100 places to go in the Internet only a few years ago), but you can find everything you need by just typing a few keywords (or just a few letters, the interactively suggested keywords are usually the ones you wanted to type, showing how generic you are as an individual).

A quick test using Google with the search term *thales theorem* comes up with the image results shown in Fig. 2. This illustrates the dilemma of different naming schemes in mathematics that historically evolved in various cultures or linguistic regions: The theorem of Thales is the name of the theorem describing the ratio of parallel segments intersecting two rays in France, Poland, and other countries, while it is the name of the theorem about creating right-angled triangles by inscribing them in a half-circle in Germany, England, and other countries. Despite the inter-national and language independent facet of mathematics, we still end up with different labels for mathematical notions — even if they are based on the names of ancient mathematicians!

It is difficult or impossible to find other keywords that solve this Google-search-problem, as you see in the preceding paragraph using cumbersome descriptions avoiding the name "Thales' Theorem". There are other examples where it is even more difficult to find the right, i.e. search-engine-compatible, keywords. Looking for a *pie chart* in French means to search for *camembert* — you'll hardly find resources to teach statistics if you search for that.

The barriers to cross [15] are manifold. Language is one of them, although it should not be. But even in the same idiom you cannot express the multitude of meanings in a few keywords that you need for quickly locating the best fit for your next lesson. Are you looking for proofs of the Pythagorean theorem? Or do you want to introduce it? Or let students use it for proving something else? Or apply it in some exercises? Etc.

A structuring approach to describing your particular learning/teaching situation is to refer to *competences*, *topics* and *educational levels*. They are a tool to formalize expectations and prerequisites. Most modern curricula are based on competence formulations, as opposed to *content* formulations, because the educational paradigm shifted from accumulating knowledge to process orientation — we want to know what a student can do with what he learned, how he can transfer all those lessons into active participation in society.

Before Intergeo, there was no structured description of mathematical competences available that could cover all (or at least *all European*) curricula. That gave rise to the development of GeoSkills, an ontology, that is a structured formal description including the relations between the things described [14]. This ontology can be used for metadata of resources, telling as exactly as possible for what audience the resource is intended, what competences the students need to have in order to work with the resource, and what competences they may acquire working with it. Also, the ontology features topics — still an important classification within the wide field of mathematics — that serve as a content-oriented description of a resource.

Now, this changes the whole process of *searching by keyword* into *searching by competence or topic*. Once a node from the GeoSkills ontology has been selected, it is easy for a search engine to select those resources that match that competence or topic, or a semantically nearby competence or topic. It is not clear, however, how these nodes could be selected. After all, we are still typing keywords. The Intergeo platform i2geo.net, based on the educational platform Curriki [4], offers a search field that automatically matches keywords into selectable nodes in the ontology, based on the

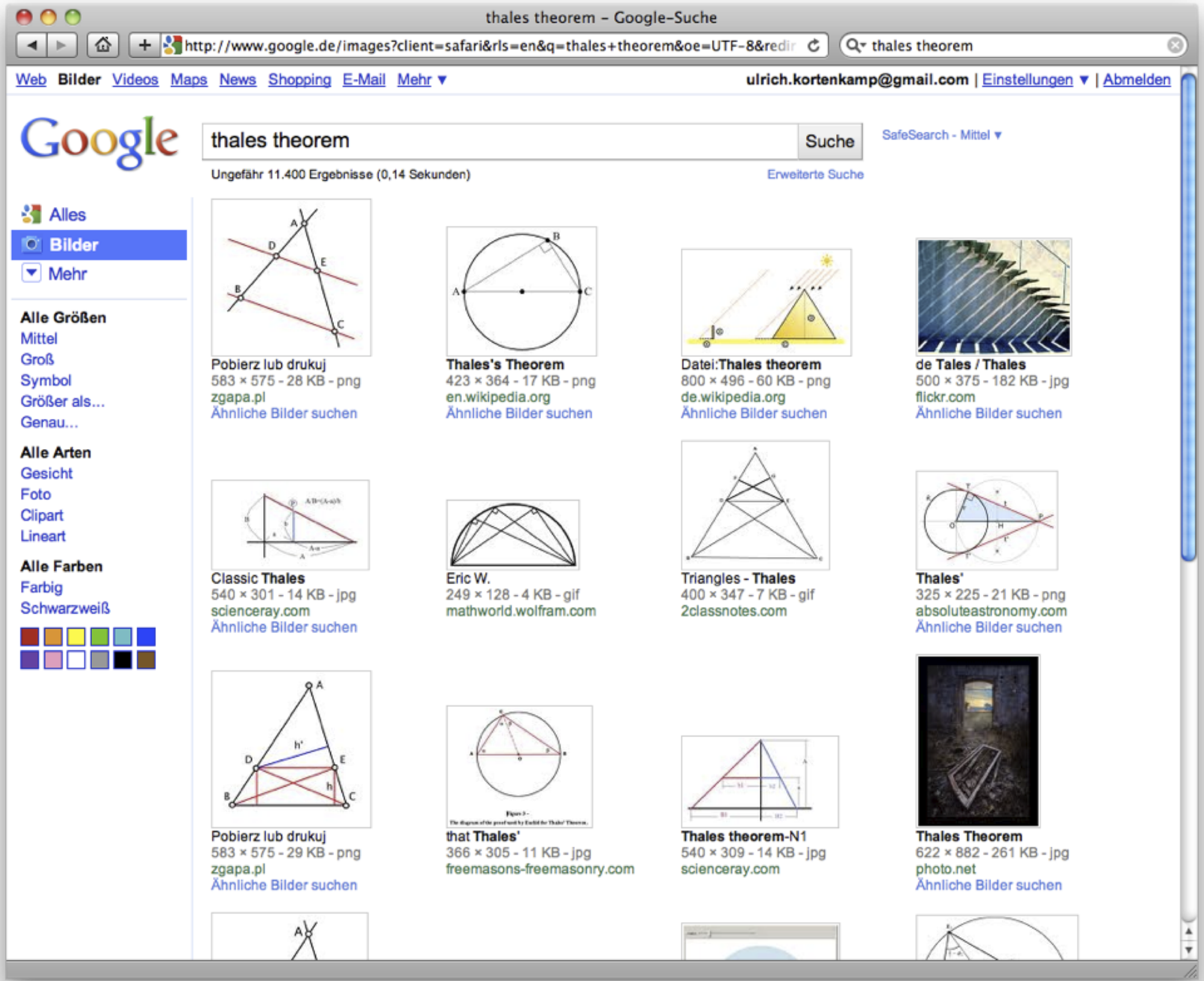

Figure 4: Google image search for *thales theorem*. Some of the images depict non-right-angled triangles, other depict circles and right-angled triangles. To the user it is not clear why this is the case.

Figure 5: The Intergeo ontology-based search tool

users' language.

Let us look back on the Thales example: A French teacher typing "thales" will be offered the corresponding competences related to similar triangles, ratios, etc., while a German teacher will be able to choose from the competences related to right-angled triangles, inscribed angles, etc. Both will also be offered the topic "Thales Theorem" (resp. "théorème de Thalès" in French and "Satz des Thales" in German) and corresponding competences, but also in that case the underlying competence in the ontology differs. Both will choose different nodes when they choose that similar sounding competence.

This, in short, describes the difference of the ontology-based search to the keyword-based search as known from ordinary search engines. While specifying the desired result much more exactly, the users have the comfort of keyword-based search. In order for this to work, all the resources need proper metadata in terms of the ontology. For the more than 3000 resources provided by Intergeo project this has been added already, for user-contributed resources it is as easy to add the correct competence as to search for it.

Another aspect of providing proper and structured metadata is the ability to remove duplicates from search results, in particular if resources are re-used (modified, extended, translated into another language, re-designed, embedded into other courses, ...), traditional search engines cannot cluster these search results into one. In that case, instead of getting a variety of different resources, a long list of similar resources is presented.

Of course, Google (or Bing) is still the first choice for searches. But using the approach developed within Intergeo and the metadata added by it we can even hope that this will be integrated in the near future into their search engines. Then, a Spanish teacher will find the right resources when searching for “teorema de thales” — do *you* know what he is looking for?

3 Use — Crossing Technology Barriers

Assuming that it is possible to *find* the fitting resource for your next lesson, it is still not guaranteed that you will be able to use it. Even if you have access to one or several computers or other devices in the classroom, that is, if there is the possibility to use interactive geometry at all, you still need the proper software to use the resource.

Fortunately, most of the resources on the i2geo.net platform can be used immediately in the web browser of your choice, because there exists suitable plugins for running Flash- or Java-based content. Actually, the JSXgraph project [30], originating from the GEONExT group in Bayreuth, is based on JavaScript, a well-performing scripting language built into all modern browsers. So, the problem stated in the preceding paragraph does not seem to have high impact at first sight. We will give technical and pedagogical reasons why this browser-based solution is not sufficient.

While the current generation of browsers does support the Java, Flash and Javascript technology mentioned above, there is evidence that this support will not last forever. Apple Inc. proved its strength by explicitly not supporting the Flash plugin, first on its mobile iOS devices (iPhone and iPad), now also with small notebooks (the latest generation of the MacBook Air no longer ships with Flash). On the mobile devices, there is also no support for Java, and Apple gave up the responsibility for the Java runtime environment on Mac OS by releasing some of the code the OpenJDK project. With the acquisition of Sun Microsystems by Oracle the future of Desktop Java suitable for interactive geometry is unsure. Once it is decided that Java is only necessary for server solutions, it might become unsupported in the next generation of web browsers. There is no hint that JavaScript will die soon, in fact its future looks bright, but this can change within a few years as it did for Flash and Java.

A lack of plugins for Java and Flash would mean that most of the resources will no longer play directly in the browser, but they must be downloaded and used with the corresponding desktop software – if that still exists. A complete rewrite of the existing software in another language seems to be unrealistic – the JSXgraph project shows that starting from scratch opens many opportunities, but also needs a lot of manpower just to reach the same features that have been able years ago. JSXgraph still lacks a suitable user interface for student interaction and can only be used either as a player for constructions created with other software, or by users with the required programming skills in Javascript.

This leads us to the pedagogical issues: An important contribution of interactive geometry software is that it can be used for self-directed student explorations. In such learning scenarios, where students create, discuss, discover, explore, suppose, prove and disprove, they have to be able to organize their learning by themselves. This includes the ability to *store* intermediate work, *exchange* files with others, *print* and *categorize* several instances of their work, etc. These are concepts that are currently not supported well by web-based applications. There are approaches to use Web 2.0 for such explorations [23], but they cannot fully replace the basic tools that the computers' operating system offers, with the access to a file system being the most important one.

Another issue was raised by Matija Lokar of the nauk.si project [16]: Most users want to be able to *modify* resources (though most users don't do it). Thus, they can adapt the content to their specific teaching situation by translating it, adding to it, removing from it, changing notation to suit the conventions of the curriculum, etc.

We have seen that it is necessary to distinguish between (a) the resource and (b) the software that is needed to use the resource. We cannot view the resource as a self-contained entity, even if the in-browser-playing Java applets may look like such.

If we provide the resources, part (a), then we have to make sure that the user has access to part (b), the software. Unfortunately, as of today it is usually not possible to open a resource created with one interactive geometry software with another one. All software uses its own proprietary format – some are XML-based, some are text files, others are binary, some are documented, most are not. Also, not all software is available for each platform, and only some software is available for free, others have to be licensed.

Although each software for interactive geometry has its own unique features, there are many similarities and basic properties that they all share. Most constructions can be done in any software (though there are subtle differences even with basic operations, see [18]). A solution to the resource-software mismatch problem would be that each software should try to read the others' format. With the growing number of interactive geometry software systems, even if we only consider major ones, this is extremely unrealistic.

For these reasons, the participating software developers and mathematical knowledge representation experts in the Intergeo project decided to design a file format [1] that is

- Extendable
- Open and documented, and
- Standardized.

The first format specification was published in Deliverable D3.3 [6] of the project, with a revised version following in Deliverable D3.6 [7].

In order to sustain the work on the file format and to ensure that the file format and the associated API [11] will be available in the future without the availability of the Intergeo project consortium, the non-profit organization Intergeo A.s.b.l. was founded in Luxembourg [12]. With the software partners of Intergeo being members in that organization there is an independent body that will be responsible for official implementations and extensions of the i2g format.

4 Quality — Know What's Good

Even if a resource was found and is ready to use, a teacher still might hesitate to expose his class to it, as she does have no information about the quality of it. Resources on the web as found, for example, in private websites receive no editing like a textbook does. There is no peer-review for such resources like there is for journal articles. Although a teacher might be able to judge the suitability of a resource for her teaching in advance just by looking at it, this is by no means more than just a hint. The quality of a resource is a multifaceted matter that depends on a lot of variables – starting with the teacher, her experience, the class and the students' experiences, the technological setup, the added value of the resource compared to traditional teaching, etc.

To really assess a resource it is essential to conduct tests in the classroom. The settings of these tests have to be recorded as additional data that will influence the interpretation of any rating given. On the Intergeo platform we allow any registered user to submit reviews of resources. In our guidelines for external testing [21] we describe the recommended procedures and urge users to base tests not only on their expert opinion, but preferably on experiments in the classroom.

In order to ignite the contribution of reviews for resources, the Intergeo partners did reviews for several hundreds of resources, most of them based on classroom experiments. We encourage everybody to submit their own reviews.

Actually, doing reviews for Intergeo does not only benefit other users who can use this data for selecting resources, but it is also of advantage for the reviewers themselves: An important lesson learned for us was the tight integration of professional development of teachers and using the quality assessment tool of the i2geo platform. As becoming an expert in the use of DGS for teaching is, by nature, an evolutionary process that needs time and continuous reflection of the own acting in the classroom, we cannot expect anybody to do perfect reviews from the beginning. Instead, by reviewing, teachers can develop their abilities to judge their own and others' material and the use of it. By asking specific questions we stimulate teachers to think about the real benefit of a resource for their teaching. This reflection enables teachers to better purpose the resources in their own classroom actions.

The quality assessment tool of Intergeo supports this quality process [25, 27] by adapting to the reviewers' expertise. Any review can be quickly done by just specifying the classroom setting and, if different from the recommend one, educational level of the students, and then answering 8 questions relating to technical, pedagogical, organizational and mathematical aspects:

- I found easily the resource, the audience, competencies and themes are adequate
- The files are technically sound and easy to open
- The content is mathematically sound and usable in the classroom
- Translation of the mathematical activity into interactive geometry is coherent
- In this resource, Interactive Geometry adds value to the learning experience
- This activity helps me teach mathematics
- I know how to set my class for this activity
- I found easily a way to use this activity in my curriculum progression
- The resource is user friendly and adaptable

The reviewer can agree or disagree with each of the statements on a four-point Likert scale, where each covers a different aspect of quality. For expert teachers and for those, who want to know more specifically how, for example, an activity might help to teach mathematics, each of the items in the

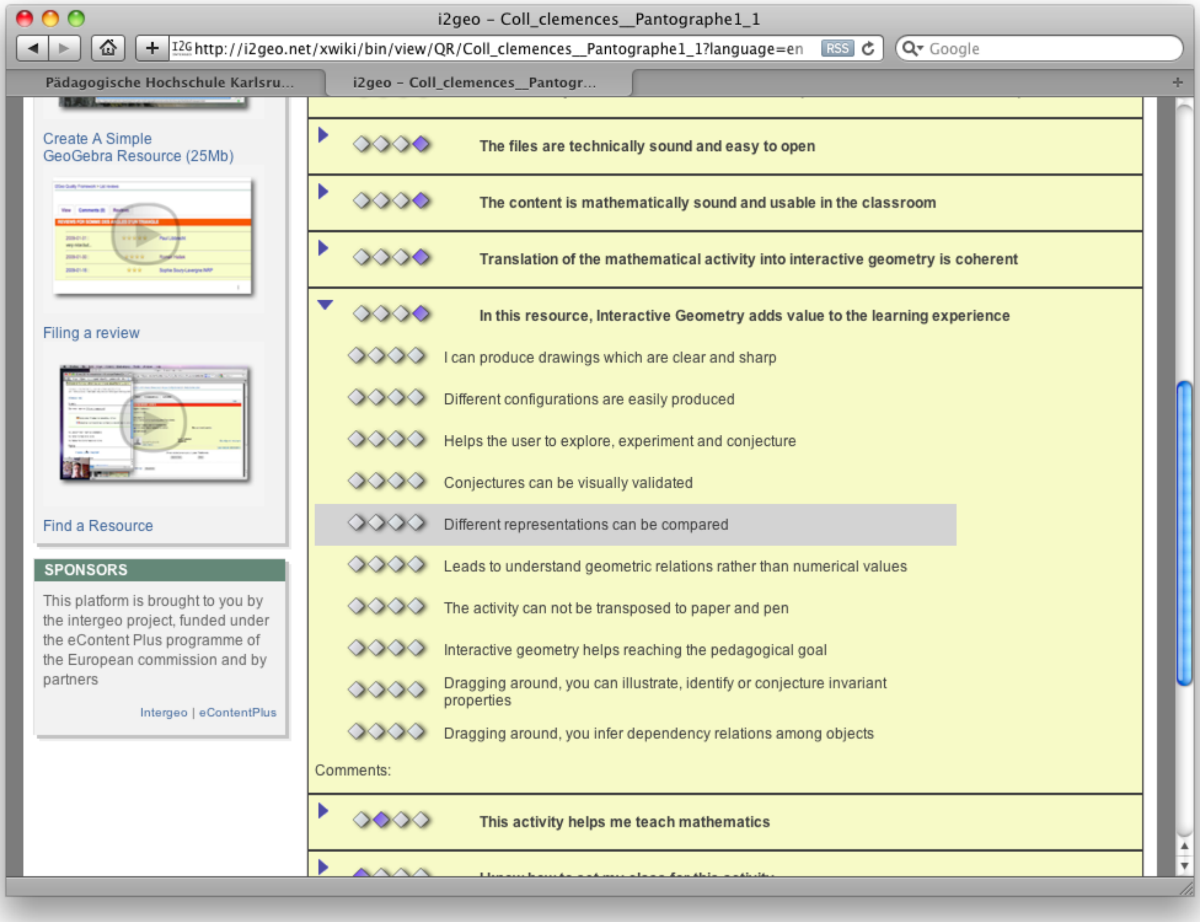

Figure 6: The Quality Assessment tool of i2geo.net. Each of the 8 fundamental statements can be expanded to a set of fine-grained items.

questionnaire can be expanded to a set of fine-grained statements that belong to this area 4. Answering these detail questions increases the usefulness of the review, and also increases its credibility.

Intergeo uses a *Karma-point* system [2, 19] for ordering the search results. The ranking in the search results does not only depend on the score of the review, but also on the reliability of the review that depends both on the detailedness of it and the Karma of the author. This system has been implemented recently [15] and should help to keep the editorial work on the platform at a minimum while still returning useful results and being less prone to vandalism and spam.

5 Conclusion and Future Work

It is necessary to offer teachers access to the wealth of resources for technology-based teaching. In this article we tried to show how we approached some of the problems that arise for teachers in service. Despite the availability of lots of content, it is not straightforward to find and use resources, in particular if a certain quality standard should be maintained. Intergeo, an effort of the major European players in interactive geometry, spent three years to remedy this situation [26].

While providing a theory-based implementation of a solution to the three problems raised in the preceding three sections, the Intergeo project still faces several challenges that have to be addressed in the next years. First, the number of users, both consumers and contributors, of the platform must be increased. This was not possible during the first years, mainly due to the lack of a working platform. By now, we could show how to use i2geo.net successfully in teachers' workshops and in teacher education at the university. Teachers who learned how to use the platform can use it in their everyday teaching. It is now a matter of advertising the platform and integrating it into teachers' professional development.

The Geoskills ontology for competences, topics and educational levels in mathematics education is complete, but it is missing many translations into the languages commonly used in the European Union. Also, only very few of the countries of the European Union are covered by the *curriculum encodings* available on the platform. A curriculum encoding is a curriculum text (either an official publication of a ministry of education, or a school curriculum, or the table of contents of a textbook, or any other description of topics and competences for a given educational situation) that is annotated with clickable links to the ontology resulting in queries for related material. The project provides the necessary infrastructure for adding more such texts, and we are in contact with textbook publishers who showed interest in publishing their content.

This and other tasks around the Intergeo platform will be addressed within the next months in order to create a working tool for resource distribution, exchange, and rating, that can be used both by teachers as well as research teams all over Europe and the rest of the world.

6 Electronic Materials

1. Cinderella file for Figure 2
2. HTML file for Figure 2
3. Cinderella file for Figure 3
4. HTML file for Figure 3

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