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Using Learning Maps for Visualization of Adaptive Learning Path Components

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***Abstract*: Most e-learning courses are still offered linearly as online book supplemented by interactive media and exercises. Therefore representing the whole content of an e-learning course by some kind of hierarchical table of content is sufficient. When using an adaptive e-learning system, individual learning paths may be used and suggested to the users, e.g. in dependence of a given answer of an exercise. This paper presents our extended concept how to represent such e-learning content of an adaptive system using the metaphor of a map. The work incorporates different perspectives from cartography and geomatics, pedagogy, didactics, information visualization and computer science into a practicable method for representing e-learning content as learning map using cities for learning units and buildings for knowledge units. Therefore this work might also be considered in the discussion of spatial turn.**

Keywords: e-learning, cartography, learning maps, adaptive learning

I. Introduction

Using a classic table of content inherited from written literature is limited in representing adaptive e-learning content. We introduce an extended concept [1] to visualize e-learning courses using a map metaphor incorporating *web-didactics* [2], [3] and *adaptive learning paths* [4]. In result, this means for example to visualize learning units as cities, learning paths as roads and tests as obstacles like mountains or lakes.

The term *learning map* is treated as a specialized knowledge map [5] in this context with emphasis on e-learning and visualization of digital learning objects. In the technical discipline of cartography it is still quite new to apply methods of geodata representation [6] for visualizing *non-spatial* information, especially e-learning content. The idea of using the metaphor of a cartographic map offers a non technical view to the learner which gives an overview of the learning content and in addition may contribute motivation. Furthermore it matches the networked character of adaptive e-learning content. In order to find a suitable representation, methods of cartographic representation and map related representations such as block diagram, globe and 3D-visualization were examined. Furthermore interaction possibilities from geographic information systems like zooming, filtering, buffering etc. were analyzed for transferability. Afterwards a visualization concept and a prototype were developed, showing the representation of the e-learning content at different zooming levels and the interaction concept of the integrated tools.

II. Didactic Framework

Adaptive learning systems are able to adapt the presented e-learning content to the individual learner in accordance to her/his learning habits (*user model*), learning situation (*situation model*) and learning performance.

As the learning performance is mostly represented by results of given exercises, monitoring the learning progress is a first step for adaption for example in degree of accomplished educational objectives according to Bloom's Revised Taxonomy [7].

A. Web-Didactics

According to web-didactics an adaptive learning path or the route a learner "takes through the semantic network (through the material)" is called learning navigation or just navigation [8]. This navigation is part of the *macro structure* which describes the connection of learning units. Learning units (as term of web-didactics) themselves are formed by sets of knowledge units – see Figure 1 – which are semantically enriched by knowledge type, media type (presentation, communication, interaction) and competency level.

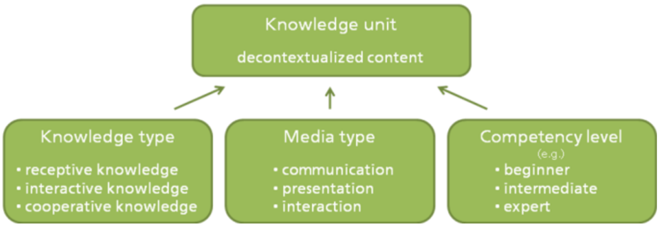


Figure 1: Structure of a knowledge unit

Knowledge type is differentiated into receptive, interactive and cooperative knowledge.

Receptive knowledge types are passively perceived [9], [10] and differentiated in:

- *orientation knowledge* like facts, history, overview and abstract,
- *explanation knowledge* like definition, argument, example and comment,
- *action knowledge* like checklist, instruction and rules,
- and *source knowledge* like list of literature, general references and download instructions.

Interactive knowledge types are distinguished in:

- different *assignments* like exercise (discovery, matching, order, spelling) and repetition (drill & practice)
- and *interactive video and animation* (like simulation).

Cooperative knowledge types are grouped by occurrence in:

- *planned cooperation* like consulting, workgroup, role-play, discussion
- and *unplanned cooperation* like spontaneous chats and questions to instructors.

Based on this metadata different views of a learning unit may be generated (if sufficient knowledge units are available) following different rules like theory driven or example driven or even a sensory oriented choice of knowledge units (micro-structure).

For example, if a student likes to work with static content, the system will use mostly texts and graphics. If a student prefers exploration, the system will increase the usage of interactive animations and simulations.

Furthermore different learning paths (macro structure) may be also created manually. From a didactic point of view these different paths can be used to offer different 'ways' to reach a given learning objective – see Figure 2.

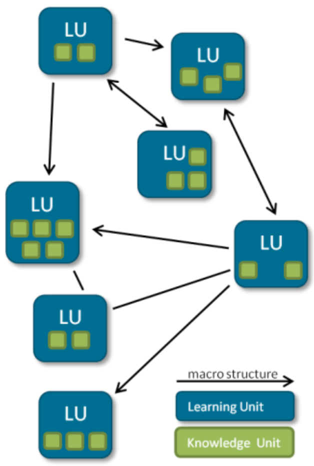


Figure 2: Related learning units (macro structure), each formed by different knowledge units (micro structure)

B. Adaptive learning paths – macro structure

A learning path in general describes how learning units of a course are connected. In a linear learning path learning units simply have one predecessor and one successor.

In adaptive learning paths the structure can vary, leading to a complex graph of successors and predecessors, whereas a learning unit (LU) is a vertex and the connection is the edge – see Figure 3.

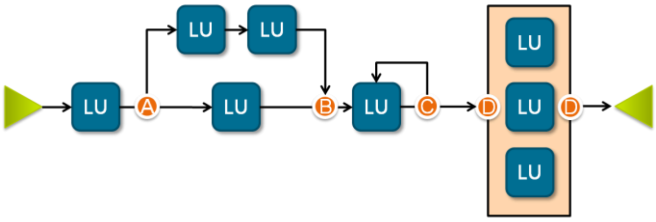


Figure 3: example graph with the components branch A, confluence B, repeat C and optional sequence D

Adaptive learning paths want to adapt to the knowledge of a student, presenting him the ideal path through the course with the right amount of challenge, meaning neither an insufficient challenge nor an excessive challenge according to individual skills.

In order to decide which edge a student should follow, the system can use exercises and tests. So after a learning unit or a set of learning units it is necessary to apply a test in order to find out which level of knowledge the student has achieved. According to the test results the system can then compute which path option (edge) would fit best for the individual knowledge of the student. These tests ideally are part of the didactic design of the learning unit, but don't have to be part of it, since it is a separated way for a system to adapt to the current status of the student skills.

When the system automatically shall recommend the suitable path for a student (the so called determination logic) it is necessary to consider several dimensions.

The first dimension is *correctness* as it is vital to determine whether the answer of an exercise was correct, partly correct or false. Based on these results the system can compute a grade. But one should not consider correctness as the only dimension. For example it can be of interest whether the student solved the exercise within seconds or needed several minutes for his answer. This may be treated as dimension *speed*. You may also consider how many attempts the student needed to get to the answer, the dimension *certainty*.

Current authoring and learning environments like Crayons® [11] consider these dimensions within their adaptive learning paths. An author can provide the *correctness*, *speed* and *certainty* as quantified concepts to each exercise.

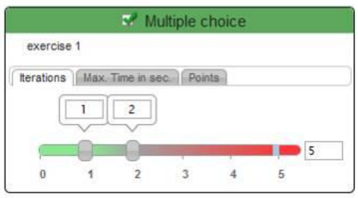


Figure 4: Example dialog, number of attempts/iterations for current multiple-choice exercise

Besides the obvious correctness criteria the author is able to set a maximum of *allowed attempts* – see Figure 4 – and a maximum of *allowed time* along with the possibility to weight the influence of these dimensions. So for example the author can instruct the system what amount of time he considers as a positive weight for the grade and which will result in a more negative weight. The determination logic considers each dimension in the exercises of a test and fetches all input of the student into its logic in order to get an overall grade for the test. The grade is computed via a set of *fuzzy logic functions* within the determination logic. This overall grade is the criteria for the edge, which will be suggested for the student. The author specifies which overall grade results in which destination edge - see Figure 5.

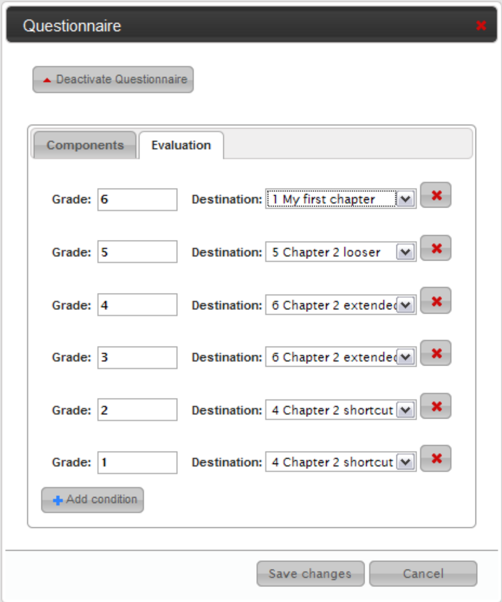


Figure 5: Allocation of grades to edges

When a student does the test and evaluates it, the system gives individual feedback and presents the suggestion (it is non-mandatory to follow the suggestion in our setting as paternalism might be an issue) which way/path he should follow – see Figure 6.

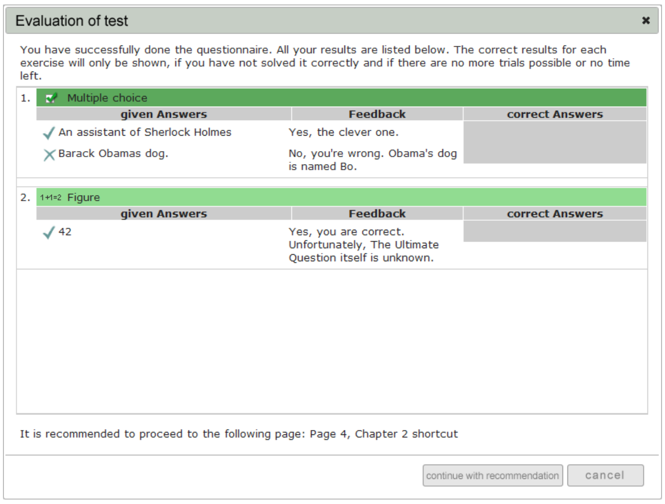


Figure 6: Feedback of test evaluation

To ensure that the student can orientate himself in the variation of edges it is necessary to provide a suitable graphical metaphor for the adaptive learning path.

III. Cartographic Framework

Different cartographic methods of representation in context of learning maps have been evaluated. In general there are *point*-, *line*- and *area*-related methods of cartographic representations. Examples are shown in Figure 7 (a-l) using the cartographic naming pattern.

The ones used in the prototype will be introduced in the following section.

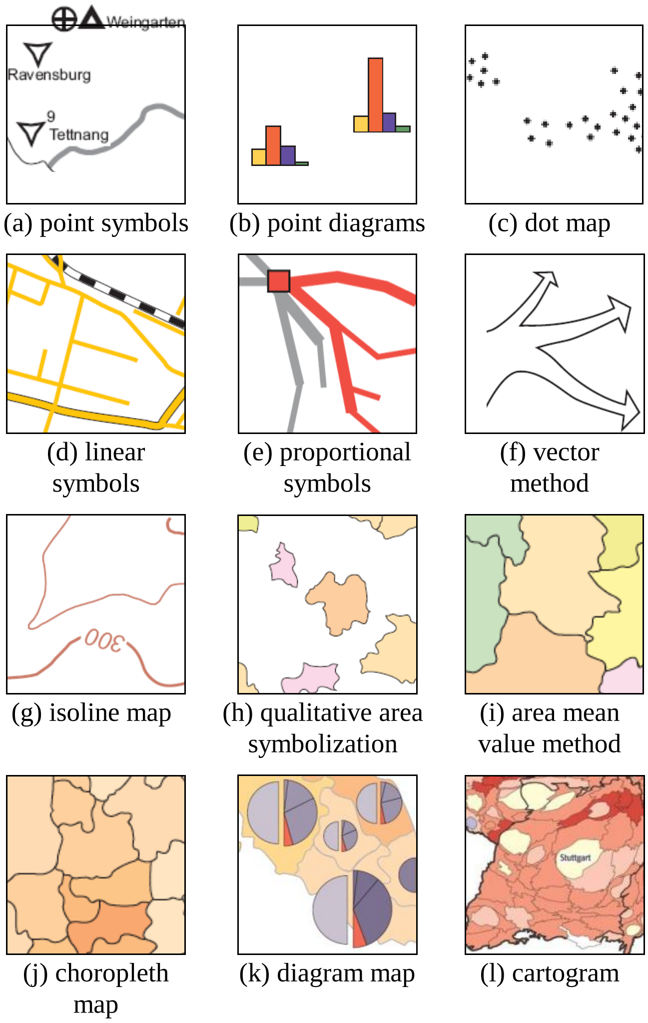


Figure 7: Different methods of cartographic representations

A. *Cartographic representation*

The method of *point symbols* (a) represents qualitative point-related data by using signatures of different colors, forms or textures.

- This method may be applied to visualize the position of the learner and is particularly suitable to visualize more than one learner. These learners could be represented through signatures of different colors.

The method of *point diagrams* (b) serves to represent quantitative point-related data by using signatures of different sizes or diagrams such as for example pie charts or bar charts to visualize several attributes of a point-related object.

- In our prototype it can be applied for representing learning units and knowledge units. The learning units can be visualized as signatures of different sizes depending on the number of included knowledge units. The bigger the signature of a learning unit, the more knowledge units it consists of.
- The knowledge units could be visualized as bar charts: the higher the bars, the higher the competency level of the knowledge unit.

The method of *linear symbols* (d) is used to show qualitative line-related information by using different colors or textures.

- This method can be applied for the visualization of the learning paths by classifying the paths into ‘walked/beaten paths’, ‘non-walked paths’, ‘system recommended paths’ and ‘voluntary paths’.

Proportional line symbols (e) serve to present quantitative line-related information by using lines of different diameter and for example are used to show traffic flow.

- For the learning map this method can be used to represent the learning paths classified according to the test results. The wider the path, the better has to be the test result, the higher is the challenge.

A. *Map signatures*

In our prototype the learning units will be represented as cities, the knowledge units they consist of as buildings, the learning paths as streets and the tests as obstacles like mountains and lakes – see sketch in Figure 8.

Of course there are other metaphors possible, like learning units as islands and tests as 'pirate ships' or 'sea monsters' which have to be 'beaten' – see examples shown in Figure 9.

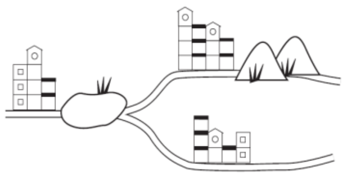


Figure 8: Metaphor of learning units as cities and knowledge units as buildings

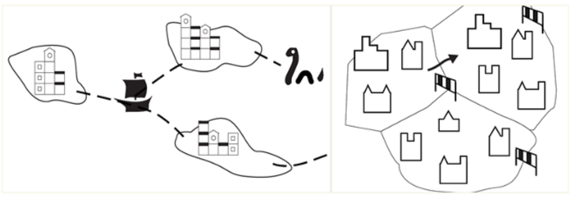


Figure 9: Sketches of different map metaphors

The following colors, shapes/forms and texture scheme are applied for our prototype:

- The media type is visualized by the texture and shape of a building.
- The competency level is represented by the number of floors.
- The colors of buildings represent the type of the knowledge units: receptive in red, interactive in blue and cooperative in yellow.
- The signatures of receptive knowledge units are designed to be associative, for example graphics are represented as buildings in the form of crayons and sounds as buildings in the form of loudspeakers.
- Athletics/Sports serve as metaphor for interactive knowledge units. Interactive films are represented by indoor swimming pools and exercises by indoor tennis courts.
- Test exercises are the only knowledge units that will not be represented as buildings but as obstacles such as mountains and lakes, as these have to be passed to proceed.
- The cooperative knowledge units are represented by call boxes (synchronous communication) and post offices (asynchronous communication).

The different graphical representation of knowledge units are shown in Figure 10.

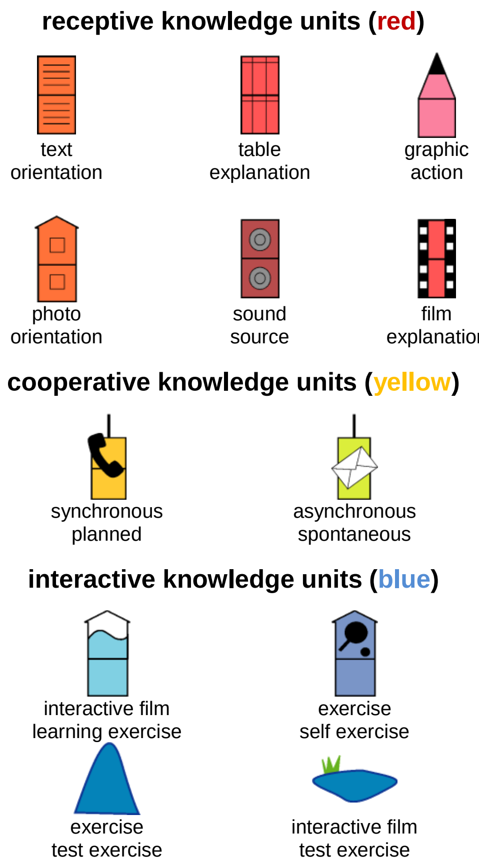


Figure 10: Graphical representation of knowledge units

B. *Learning path*

Learning paths can have different states: walked path (visualized in brown color), non-walked path (visualized in beige) and recommended path (dotted line in beige and brown). Furthermore they can be marked as voluntary (dotted line) – see Figure 11a. The *method of linear symbols* (Figure 7d) is used here.

In addition the learning paths can be represented according to the test result which is necessary so that the path can be recommended to the learner. This is done by visualizing the paths in different breadths: the broader the path, the better has to be the test result – see Figure 11b. *Proportional line symbols* (Figure 7e) are used here.

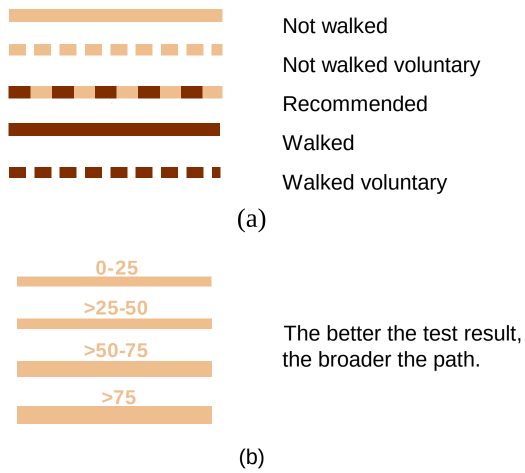


Figure 11: Visualization of learning paths

There are different learning path components. Since learning content is non-spatial data, positioning rules have to be drawn up. In the learning map the following rules should be implemented:

- The learning direction is from left to right and the path which will be walked by an average learner should usually lead linearly through the learning landscape.
- In general the learning path will be presented as a long path from left to right in our prototype as shown in Figure 14 and Figure 15. We are aware about the outline of this design and suggest also discussion of a 'serpentine'-layout as shown in Figure 12 as further improvement.
- Paths for good learners should be placed above the standard path.
- Paths which will be used by low-performing learners will be placed underneath the standard path.

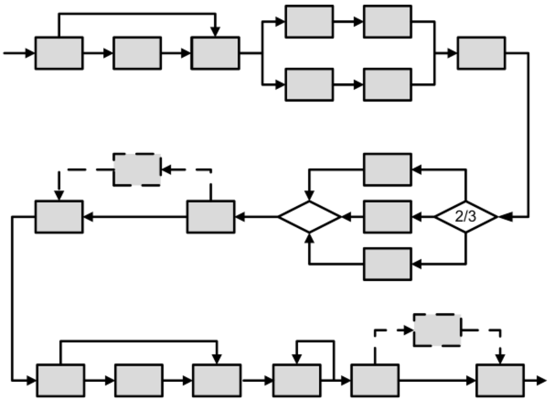
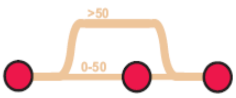
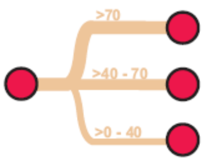


Figure 12: 'Serpentine'-layout of a learning map

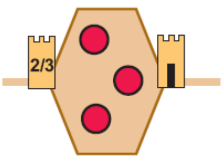
(a) cycle



(b) short cut/bypass



(c) intersection



(d) elective learning path components

(e) voluntary learning units

Figure 13: Visualizations of different path components

Figure 13 shows how the different learning path components (a-e) are visualized in our concept using the following applied rules:

- *Cycles* (a) are placed below the standard path. Since the standard learning direction is from left to right, the direction in case of a cycle is marked with one or more arrows.
- *Short cuts/bypasses* (b) are placed above the standard path. Due to the normal direction from left to right, no further arrows are presented for the learning direction.
- *Intersection* (c): Due to a defined rule the path which requires the best test result is placed at the top and the path with the worst test result is placed at the bottom.
- *Elective learning path components* (d) are visualized as cities with city walls, whereas the learning units are different parts of the city. The learner has to work through a certain number of learning units, whereupon he can choose the order in which he works through them himself. The number on the tower in front of the city indicates how many learning units (mandatory) have to be done.
- *Voluntary learning units* (e) are placed above the standard path (as dotted line) since they are e.g. for better or especially interested learners.

C. Zoom level

Starting at zoom level one (macro-structure) the learning units will be represented as point symbols of different sizes. In the same way as cities in maps are classified according to their number of residents and are represented by points and squares of different sizes, the learning units should be classified by the number of knowledge units they consist of. Thus learning units will be visualized metaphorically as cities – see Figure 14.

In the second zoom level the knowledge units (micro-structure) are now visible and represented in form of different buildings – see Figure 15. Moving the cursor over a knowledge unit in general opens a pop-up on the fly with metadata about this unit, clicking on the unit will open it.

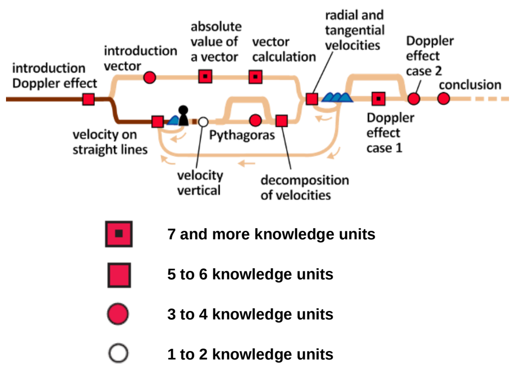


Figure 14: Zoom level macro-structure

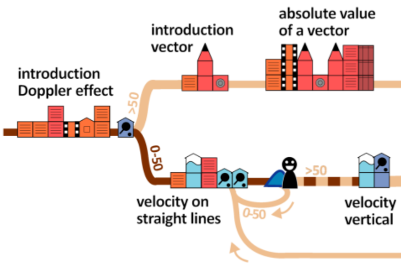


Figure 15: Zoom level micro-structure

D. *Interaction possibilities of geographic information systems*

The learning map can be designed interactive by integrating different tools and functions as they are used in geographic information systems (GIS) [12]. Functions of GIS can be divided into the categories: *navigation, data acquisition, data analysis, data processing* and *data representation*. Each of them can be transferred differently:

Functions for the *navigation* in the map like *zooming* and *panning* can be completely integrated. Other functions like *data analysis* can also be applicable. *Semantic data analysis* will be useful, if the learner wants to select learning content with certain metadata, for example he only wants to work through texts and pictures and doesn't like to watch videos/animations etc. In our prototype filtering and search functions were integrated.

In contrast - *spatial data analysis* will only be applicable if distances in the map get a useful meaning like estimated learning minutes/amount.

Furthermore functions for *data representation* and visualization can be integrated. A function to switch on/off different thematic layers is valuable. Different types of map representations could be developed, for example tools for changing from a map view into a 3D-view, for changing colors of signatures or even for choosing different metaphors. Thus the learner will be able to adapt the learning map to her/his preferences. Summary applicability of GIS-functions for e-learning content:

- navigation
  - zoom: applicable: at least two zoom levels are useful, one to give an overview, one to show the details
  - pan: applicable
  - rotate: applicable in 3D-view
  - search: applicable, gives the possibility to search for a certain topic
- data acquisition
  - digitalization: no, map will be generated automatically from the database
  - georeferencing: not applicable, due to non-spatial data
  - adding metadata: task of the author, not applicable for the learner
- data analysis
  - semantic data analysis: applicable as a filter function and useful, if the learner wants to select learning content with certain metadata
  - topologic data analysis: applicable, for example to determine adjoining learning units
  - geometric data analysis: only applicable if distances have a meaning
- data processing
  - coordinate transformation: applicable, when choosing another projection (isometric projection, 3D-view etc.)
  - generalization: will be done automatically when changing into another zoom level
- data representation
  - switching layers on/off: applicable
  - choosing colors, textures, signatures: applicable: learner will be able to adapt the learning map to his preferences
  - 3d-view: applicable
  - animation: applicable, e.g. for showing the walked route, trajectory
  - diagrams: applicable, e.g. for showing the learning success
  - profile: applicable and useful, if elevation has got a meaning, e.g. degree of difficulty

In our prototype we have chosen the elements for navigation as shown in Figure 16. These include (from left to right): zoom in, zoom out, outline view, pan, rotate, previous, next, show information/metadata, search, filter (e.g. metadata), 2d-view, isometric-view and 3d-view.

Figure 16: Toolbar to interact within the learning map

IV. Conclusion and Outlook

In brief: Methods of geodata visualization are also applicable for the visualization of non-spatial data like e-learning content.

Furthermore the metaphor map is useful for an adaptive e-learning system, as it assists its network-character. The internal graph-based connection of learning units – like shown in Figure 17 created using the toolkit Graphviz [13], [14] – may be transformed into a visual appealing valuable learning map as shown in Figure 18 (marco-zoom-level) and Figure 19 (micro-zoom-level).

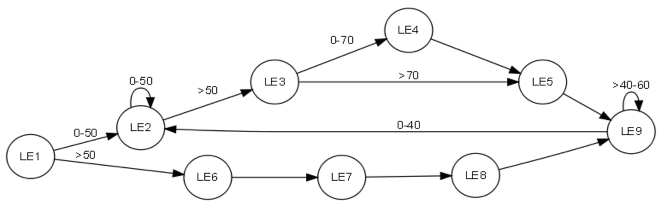


Figure 17: Learning graph created using Graphviz

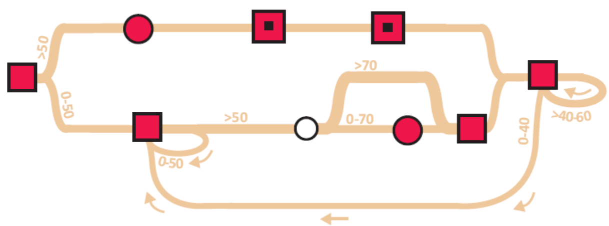


Figure 18: Learning map with applied placement rules

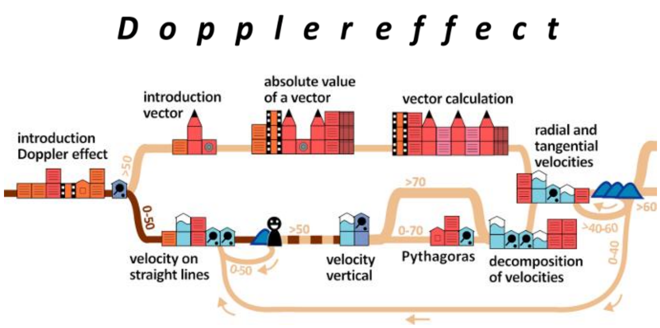


Figure 19: Learning map of 'Doppler effect' (micro-level) including labeling of knowledge units

The next step on the technical side will be the implementation of an automatic creation process. The process will create learning maps following the rules defined by the concept, as the maps in our prototype (as shown in Figure 20) have been created manually. Within this work a reasonable selection of metadata has to be determined.

Visualization of all web-didactic metadata like knowledge type, media type and competency level (including several subdivisions like receptive, orientation, explanation, action and source knowledge) as realized in our prototype only serves as an example. Parameters and attributes of the learning map should be adapted to the visualization needs according to the didactic approach of an e-learning course.

Interaction possibilities known from geographic information systems can also be integrated in such an e-learning information system. This should be interesting not only for e-learners within the geomatics disciplines or radar image interpreters we have in mind while using the SAR-Tutor [15], a computer-supported training course for the interpretation of radar images, but also in general for 'geo-services accustomed' learners who are used e.g. to tools like Google Earth and their interaction paradigms.

While applying different modules from our e-learning course SAR-Tutor to the presented map-concept we successfully created meaningful learning maps for both linear and adaptive learning paths while using different projections (2D, 2.5D-isometric, 3D) of the e-learning content – see Figure 20. A concept to gather and evaluate experiences and acceptance from tutors and learners should be undertaken in the future.

The handling of huge learning maps and its usage from the learner's perspective have also to be evaluated. One possibility is to enhance the purpose of the map by concepts from game-based learning:

Showing not only the actual learning position of *one* learner as token/meeple[1] in a game (e.g. see Figure 15 and Figure 19) but also from others working through the same course might encourage positive side effects of a competition.

These meeple can be also used as avatars for communications with others. On the other hand - a "fog of war" (as term of computer games) may be used to limit the view - e.g. not to frighten the learner with too much information and the road ahead he has to cope with.

Besides the learner's perspective, the handling of adaptive e-learning courses from the author's perspective may be also of interest for learning maps. Therefore it should be evaluated whether it is applicable or not and what concepts could be developed for that scenario. Although the author does not need visualization of the history of cities and paths he "walked through", he is asked to 'create' these cities and paths. So it may be an advantage to use the same metaphor for the author's perspective and to tailor it for his needs. Maybe it is appropriate to create a graphic enhancement allowing the author to draw and build cities whereas simultaneously the system generates the learning and knowledge units to be edited by the author. This may complement the work of a prototype of a user interface [16] for the integration of web-didactics for authors that intuitively allows the creation of learning material, while also supporting the requirements and advantages of the associated metadata as consistently as possible.

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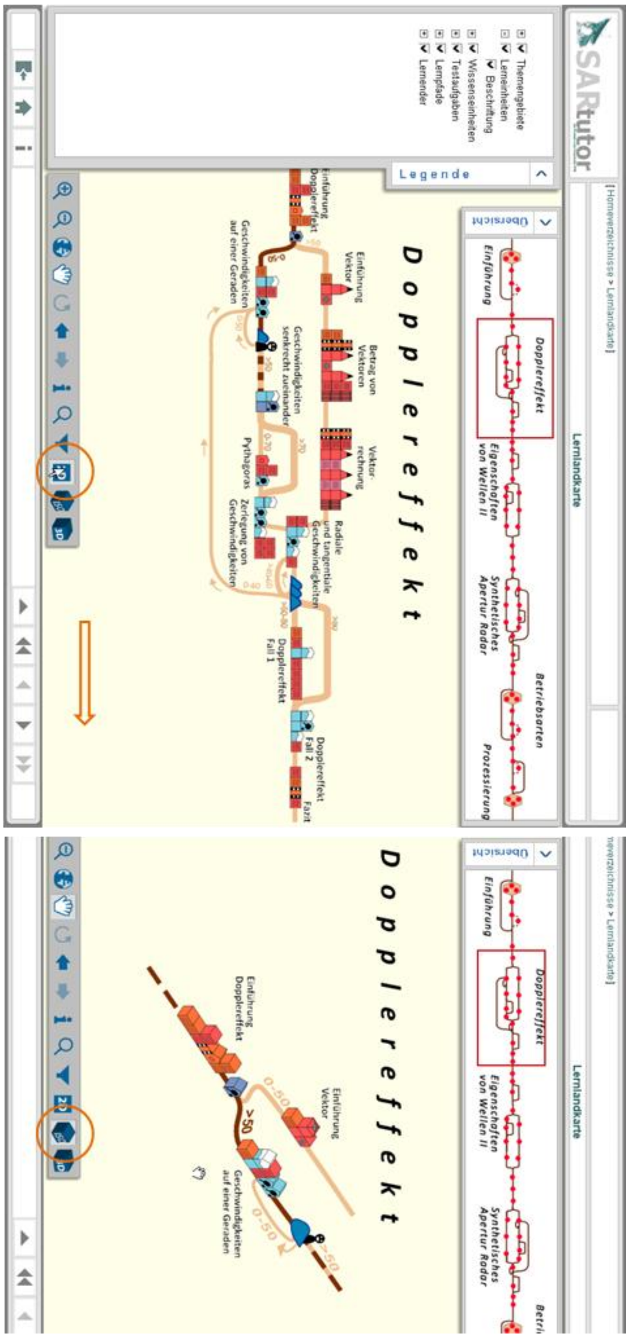

Figure 20: Learning map prototype

[1]A small person-shaped figure used as a player's token in a board game. According to Wikionary.org "meeple" is a "blend of 'my' and 'people'.

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