Interactive knowledge networks for interdisciplinary course navigation within Moodle

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The benefits of interdisciplinary learning have been addressed by a number of previous studies. In a systematic review of interdisciplinary education of undergraduate health professional students, Cooper et al. (8), for example, reported an influence on knowledge, attitudes, skills, and beliefs. Similarly, in their review on curriculum integration, Ivanitskaya et al. (20) emphasized the positive effects of the impact of interdisciplinary learning on student learning outcomes. They concluded that “as a consequence, students engaged in interdisciplinary programs are more likely to acquire integrated perspectives and solution-focused strategies, rather than content-specific knowledge derived from a single discipline.” Interdisciplinary learning means “two or more disciplines are brought together, preferably in such a way that the disciplines interact with one another and have some effect on one another’s perspectives” (27). This distinguishes it from multidisciplinary learning (15), which “refers to the involvement of several different professional areas, though not necessarily in an integrated manner” (30).

Surely interdisciplinary learning should not replace disciplinary education “since interdisciplinary courses depend on the disciplines for their perspectives as much as disciplinary courses depend on interdisciplinary ones to provide context and restraint, it may be that such a balanced curriculum would make both disciplinary and interdisciplinary courses stronger” (22).

Medical students at the Ludwig-Maximilians-Universität Munich (LMU) are taught physiology and physics in their third and fourth term. Practical courses in physics and in physiology are part of their curriculum. Contents and timing of these courses are related in an addressee-specific manner. The topics of electric circuits, resistor, capacitor, and signals are especially embedded into the physiological contexts of membrane and action potential, and the corresponding laboratory classes are synchronized in the students’ timetables. A comparison of these classes with purely monodisciplinary courses has revealed remarkable improvements in student knowledge (26). These results strengthen the notion that the linkage between both disciplines should be closer and clearer to help medical students in learning physics and discover its relations and meaning to physiology.

Better support of individual learning within interdisciplinary contexts might be a way to further enhance the efficacy of this approach. To this end, we developed a concept map-based navigation plugin for the Moodle platform (called LMUdle) (20a) for the medical faculty. This allows straightforward visualization of interdisciplinary relations with dynamic interactive concept maps. Hypermedia learning objects related to the topics of the laboratory classes in physiology and physics were created and added as a new “course” (hereafter referred to as “LMUdle course”) to LMUdle complemented with the new navigation tool. These learning objects provide the nodes of the concept map-based navigation. Content appears in various forms, such as text pages, quizzes, animations, simulations, videos and podcasts, PDF documents, and links. Our approach was designed such that adaptivity to individual users can be readily added.

Students obtained access to this hypermedia environment and could use it in addition to their traditional (not web based) face-to-face practical courses. To examine the usage and efficacy of this approach, we addressed the following research questions:

1. Does the use of additional hypermedia course contents enhance students’ increase of knowledge?
2. What is the impact of hypermedia navigation on interdisciplinary learning?
3. What kind of hypermedia learning objects do students prefer?

4. Is there a relation among individual learning time, the usage of the LMUdle course, and student learning outcomes?

5. Is there a relation between a student’s specific knowledge in a single discipline and his/her ability to transfer knowledge to interdisciplinary applications?

6. Is the LMUdle course designed to students’ needs?

MATERIALS AND METHODS

Medical students of the LMU complete practical courses in physiology and physics in their third and fourth term. These courses have previously been designed in an interdisciplinary and address-specific format (26). To complement these face-to-face courses and to facilitate individual learning, online resources were developed for and distributed via the Moodle platform LMUdle. To visualize the interdisciplinary linkage between physiology and physics and to allow simple, immediate, and user-centered orientation within a complex hypermedia environment, a Moodle extension was developed, which dynamically generates clickable concept maps. These concept maps can be used to navigate through the contents of any online course. The availability of the new learning materials within the extended Moodle is referred to as the LMUdle course.

Course Contents

The learning objects of the LMUdle course paralleled the contents of the traditional (not web based) lectures, seminars, and laboratory courses on membrane potential, action potential, and electric circuits. A questionnaire was used to guide design and development of the LMUdle course by the wishes and needs of third- and fourth-term medical students.

The preferences of different learners, such as verbalizers or visualizers, were accounted for by different learning activities, such as text pages, quizzes, animations, simulations, videos and podcasts, PDF documents, and links. Currently, these are offered in parallel without any attempt of the system to preselect materials according to user learning styles. The addition of active adaptivity to our learning environment is under development.

Moodle

The learning management system Moodle is a free open-source (GNU Public License) software package that provides a course management system for the implementation of internet-based learning environments (21a). It is an internationally widely used and successful solution to support e-learning (29) with a social constructionist framework of education (21b). Because of its modular design, it is readily extended by the installation of plugins.

Figure 1 shows the overview page and Figure 2 shows a text page of the LMUdle course as an example of a learning object. The right block, called “Semantic Web,” represents the concept map-based navigation tool developed by us and will be further discussed below in Navigation Plugin. The different navigation possibilities within the LMUdle course are marked as follows: course overview navigation (A), direct guidance (B), concept map-based navigation (C), the navigation menu (D), and text link navigation (E) in Figs. 1 and 2.

Navigation Plugin

There are several possibilities (A, D, and E in Figs. 1 and 2) used to navigate within the standard distribution of Moodle. Navigation
between courses is, however, not supported, except for the possibility of binding URLs to words or pictures. With this type of linking resources, which is, e.g., used by Wikipedia, it is very difficult to stay on top of things and not to get “lost in hyperspace” (28).

To fill this gap and to provide a clear orientation throughout navigation, we developed an extension of Moodle (hereafter referred to as Semantic Web) that combines direct guidance and two-dimensional concept map-based navigation (B and C in Fig. 1) with the standard navigation tools of Moodle (cf. Figs. 1 and 2). With it, both interdisciplinary navigation between courses and inner disciplinary navigation within one course becomes possible simultaneously.

Learning object metadata. Semantic Web works with the standards of learning object metadata developed by Hodgins and Duval (17). These metadata describe the relevant characteristics of learning objects, such as learning time, difficulty or interactivity level, taxonomy, and relations to other learning objects, as well as addition issues, such as author, copyright information, etc.

By attaching metadata to learning objects, teachers can link learning activities to already existing learning activities within any course within the whole Moodle platform.

Semantic Web. The block Semantic Web (Fig. 3) comes with two navigation possibilities: concept map-based navigation and direct guidance.

To use concept map-based navigation, students have to click on the minimap within the block. The resulting full screen-sized concept map is shown in Fig. 4. Every node represents a learning object and can be clicked to directly open the corresponding resource. The center node represents the currently visited learning object. Depending on user interactions, this map can be dynamically changed and updated. The extension of the map is controlled by the user as s/he selects the linkage depth of the concept map, meaning that s/he can choose whether s/he can see only the direct neighbors of the center node or also the neighbors of its direct neighbors and so on. The linkage depth of the map shown in Fig. 4 is two.

Direct guidance is a possibility to navigate along learning paths by simply clicking the next or back button. The learning paths are preset by the teacher and contain a special collection of learning objects selected with regard to a common criterion, e.g., a visual path, a verbal...
Learning paths are integrated and visualized within our navigation map as colored lines between the nodes. The top right caption in Fig. 4 explains the meaning of the paths. Students can select the path they want to navigate along. In Fig. 3, the path “cellular excitation” was selected.

Learning objects of the whole Moodle environment can be linked to each other within a single navigation map. It is also possible (and recommended) to organize the connections in subject groups called “bundles.” In our case, we built a single bundle of physiology and physics contents. This allows students to generate maps restricted to physiology and physics; links to contents outside the chosen bundle will not be considered when the concept map is generated.

To support direct guidance, learning paths have to be built by setting the name, description, and color of the path as well as its nodes in a meaningful order.

The Semantic Web extension is integrated in Moodle’s role management, so the administrator can manage the rights for block configuration and usage in the same way as it works within the standard distribution.

Research Design

Instruments. To examine learning outcomes, students had to complete knowledge pre- and posttests. These questionnaires contained 18 multiple-choice questions (see the APPENDIX), with 6 questions for each of the three categories of medicine (physiology), physics, and transfer. Each question had four possible answers in addition to the option of “I don’t know.” Exactly one answer was correct.

Additional questions were aimed at the students’ satisfaction with the LMUdle course and the Semantic Web extension as well as their learning behavior.

Moreover, the students’ navigation behavior within the LMUdle course was tracked by the system.

Procedures. Before students started with their normal 2-wk course sequence on membrane potential, action potential, and electric circuits, they filled out the knowledge pretest questionnaire. Thereafter, they completed the posttest. Once the students of the term 2011 group (see Samples) had finished the pretest, they obtained access to the LMUdle course. Students were free in their decision on how to use this course. Students had worked with the LMUdle platform since their first term; thus, they were familiar with it at the time of this study. Use of the Semantic Web navigation plugin was explained by a video within the LMUdle course. During the time interval between the pre- and posttest, every navigation step made by participants of the study within the LMUdle course was tracked. As the students’ identities were encoded by a unique pseudonym and participation was voluntary, Institutional Review Board approval was not required.

Samples. In 2010 and 2011, there were each ~800 students entered into the courses in physiology and physics. They were divided randomly into 40 groups of 20 participants. Groups for inclusion into the term 2010 or term 2011 groups were selected without knowledge of individual participants or course teachers (see Table 1). The term 2011 group was divided into the two sample groups (LMUdle and Traditional) depending on whether the students used the LMUdle course or not.
Table 1. Sample groups used in the present study

<table>
<thead>
<tr>
<th>Description</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term 2010</td>
<td>292</td>
</tr>
<tr>
<td>Term 2011</td>
<td>320</td>
</tr>
<tr>
<td>LMUdle</td>
<td>33</td>
</tr>
<tr>
<td>Traditional</td>
<td>287</td>
</tr>
</tbody>
</table>

The term 2010 and term 2011 sample groups significantly differed with respect to the results of the knowledge pretest \((P = 0.002)\), whereas the posttest results were similar \((P = 0.99)\). The LMUdle and Traditional groups did not differ in prior knowledge \((P = 0.83)\). Thus, the learning outcomes of the LMUdle and Traditional groups could be compared, and test analysis could be accomplished with the use of all sample posttest results.

**Statistical Analysis**

Test analysis. The quality of a knowledge test was determined by Cronbach’s \(\alpha\) \((9, 12)\) and the approaches of analyzing multiple-choice tests by Ding and Beichner \((11)\). Table 2 shows the parameters and their range of acceptable values.

Thus, Cronbach’s \(\alpha\), Ferguson’s \(\delta\), the item difficulty index, the item discrimination index \((D)\), and the point biserial coefficient \((r_{pb})\) were calculated.

Cronbach’s \(\alpha\) indicates the internal consistency of the test. A value of Cronbach’s \(\alpha\) of >0.70 means that the test is precise enough to measure group effects. Ferguson’s \(\delta\) quantifies the discriminatory power of the entire test. Higher values represent broader score distributions. A Ferguson’s \(\delta\) value of >0.90 indicates good discrimination among students. The \(D\) value denotes how powerful a single test item distinguishes students with respect to their achievement. Values of \(D \geq 0.30\) represent an adopted standard \((12)\). The relative frequency of correct answers of a test item is provided by the item difficulty index. Good items are both not too easy and not too difficult, represented by values of the range between 0.30 and 0.90. The correlation between the score of one item and the total score of the test is defined as \(r_{pb}\). Values of reliable items are >0.20.

\(t\)-test and \(U\)-test. The statistics software SPSS was used to calculate \(t\)-tests and \(U\)-tests. SPSS automatically performs a \(t\)-test with every \(t\)-test to check the homogeneity of both samples’ variances. Accordingly, pretest comparison of the term 2010 and term 2011 groups was done by \(t\)-test for equal sample variances. Posttest comparisons were performed using a \(t\)-test for unequal variances.

Because the sizes of the LMUdle and Traditional sample groups were very different and the knowledge increase was not normally distributed, a \(U\)-test was used to compare the knowledge increase between these samples.

Effect size. Cohen’s \(d\) (Eq. 1) was used to quantify the effect size, as follows:

\[
d = \frac{\bar{X}_1 - \bar{X}_2}{S}
\]

where \(X_1\) is the mean of group \(i\) and \(S\) is the standard deviation. While Cohen assumed that the standard deviations of both samples are equal \((S = S_1 = S_2)\) \((7)\), other authors account for unequal sample sizes and standard deviations using the square root of the pooled variance \(S^2\) (Eq. 2), as follows \((16)\):

\[
s^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2}
\]

where \(n_i\) is the size of sample \(i\) and \(S^2\) is variance of sample \(i\).

Path analysis. Path analysis, as described by Duncan \((13)\), is a statistical procedure to explore or verify causal linear models. Path analysis contains a set of linear regression analyses to describe the relations between exogenous (independent of the variables within the model) and endogenous (dependencies explained within the model) variables. These variables may also be latent (not directly observable), such as motivation or physiological knowledge.

A structural equation model containing latent variables is composed of measure models and a structural model. Measure models contain a latent variable and manifest indicator variables, such as test items. The latent variable is examined by these indicator variables. The structural model explains the relations between latent variables.

A path diagram is the graphic representation of the underlying linear structural equations. There are some conventions to a path diagram: one-way straight arrows point from the determining variable to the variable depending on it. Two-headed curved arrows show unanalyzed correlations between exogenous variables. Path coefficients can be interpreted as regression coefficients (straight arrows) and correlation coefficients (curved arrows), so they show the direct effects between variables. With the aid of path coefficients, indirect and total effects can also be computed \((1)\).

To assess the goodness of fit of the hypothesized model to sample data, the root mean square error of approximation \((RMSEA)\) was calculated. MacCallum et al. \((21)\) explained that a RMSEA value \((\varepsilon)\) of <0.05 may be considered as indicative of close fit, whereas values of 0.08 – 0.10 indicate a mediocre fit. Another fit index is the ratio of \(\chi^2\) to degrees of freedom \((df)\), which has to be <2.5 for an acceptable model. If the assumption of multivariate normal distribution of variables is not met, the model may also be assessed by the corrected \(P\) value as recommended by Bollen and Stine \((3)\). A significant result \((P < 0.05)\) means that the model has to be rejected.

These indexes result from the analysis of discrepancy between the estimated population values and sample values of covariances between the variables of the model (latent variables, indicator variables, and residuals). A discrepancy function \((F)\) is used to determine this difference. For the best-fitting model parameters, \(F\) achieves a minimum: the \(F_0\) value. The RMSEA indicates the discrepancy per \(df\) and is defined as follows in Eq. 3:

\[
\varepsilon = \sqrt{\frac{F_0}{df}}
\]

where \(\hat{F}_0\) is the estimated value of \(F_0\). Path analysis in this study was done with the aid of the statistics software SPSS Amos \((19a)\).

**Navigation structure analysis.** A network of learning objects (nodes) connected by all users’ navigation steps was used to visualize the learning paths within the LMUdle course. Figure 5 shows an example of such a network. An interactive data visualization can be found at http://www.dasis.mecum-online.de/study/navsteps.php.

To evaluate the diversity of the users’ navigation paths, the global navigation fashion was quantified by a value, which we called the specific linkage measure \((lm)\). \(lm\) was defined as follows:
Table 3. Analysis of knowledge test items

<table>
<thead>
<tr>
<th>Knowledge Test Item</th>
<th>Knowledge Type</th>
<th>Difficulty Index</th>
<th>D</th>
<th>r_{ps}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1. Definition of electric voltage</td>
<td>P</td>
<td>0.70</td>
<td>0.38</td>
<td>0.33</td>
</tr>
<tr>
<td>Question 2. Voltage = work/flow and the Nernst equation</td>
<td>T</td>
<td>0.42</td>
<td>0.45</td>
<td>0.31</td>
</tr>
<tr>
<td>Question 3. Membrane potential and permeability</td>
<td>M</td>
<td>0.69</td>
<td>0.40</td>
<td>0.37</td>
</tr>
<tr>
<td>Question 4. Characteristic curve of Ohm’s resistor</td>
<td>P</td>
<td>0.17</td>
<td>0.27</td>
<td>0.25</td>
</tr>
<tr>
<td>Question 5. Ion channel as Ohm’s resistor</td>
<td>T</td>
<td>0.46</td>
<td>0.33</td>
<td>0.25</td>
</tr>
<tr>
<td>Question 6. Sodium-potassium pump</td>
<td>M</td>
<td>0.85</td>
<td>0.28</td>
<td>0.31</td>
</tr>
<tr>
<td>Question 7. Refraction time</td>
<td>M</td>
<td>0.75</td>
<td>0.51</td>
<td>0.45</td>
</tr>
<tr>
<td>Question 8. Parallel ion channels</td>
<td>T</td>
<td>0.11</td>
<td>0.22</td>
<td>0.27</td>
</tr>
<tr>
<td>Question 9. Parallel circuit of resistors</td>
<td>P</td>
<td>0.30</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>Question 10. Specific resistivity</td>
<td>P</td>
<td>0.83</td>
<td>0.32</td>
<td>0.38</td>
</tr>
<tr>
<td>Question 11. Cross-sectional area of an axon</td>
<td>T</td>
<td>0.90</td>
<td>0.26</td>
<td>0.41</td>
</tr>
<tr>
<td>Question 12. Stimulus amplitude encoded by frequency</td>
<td>M</td>
<td>0.36</td>
<td>0.67</td>
<td>0.48</td>
</tr>
<tr>
<td>Question 13. Capacitance of a capacitor</td>
<td>P</td>
<td>0.82</td>
<td>0.41</td>
<td>0.44</td>
</tr>
<tr>
<td>Question 14. Membrane as a capacitor</td>
<td>T</td>
<td>0.28</td>
<td>0.51</td>
<td>0.36</td>
</tr>
<tr>
<td>Question 15. Myelination of an axon</td>
<td>M</td>
<td>0.74</td>
<td>0.44</td>
<td>0.36</td>
</tr>
<tr>
<td>Question 16. Time constant = resistance × capacitance</td>
<td>P</td>
<td>0.84</td>
<td>0.28</td>
<td>0.30</td>
</tr>
<tr>
<td>Question 17. Membrane and ion channel as an RC element</td>
<td>T</td>
<td>0.73</td>
<td>0.38</td>
<td>0.31</td>
</tr>
<tr>
<td>Question 18. Voltage-driven sodium channel</td>
<td>M</td>
<td>0.72</td>
<td>0.51</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Types of questions were as follows: physics (P), physiology [M (for medicine)], and transfer (T).

Table 4. Comparisons between LMUdle and Traditional sample groups with respect to their increase of knowledge

<table>
<thead>
<tr>
<th>Subject</th>
<th>LMUdle Group</th>
<th>Traditional Group</th>
<th>P Value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>4.36 2.67</td>
<td>2.89 2.66</td>
<td>0.006†</td>
<td>0.55</td>
</tr>
<tr>
<td>Physics</td>
<td>2.12 1.36</td>
<td>1.70 1.46</td>
<td>0.17</td>
<td>0.29</td>
</tr>
<tr>
<td>Physiology</td>
<td>0.88 1.43</td>
<td>0.47 1.29</td>
<td>0.24</td>
<td>0.32</td>
</tr>
<tr>
<td>Transfer</td>
<td>1.36 1.25</td>
<td>0.72 1.29</td>
<td>0.01*</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Values are means and SD of differences of knowledge test scores between the pre- and posttest. *Significant at the level of 0.05, †significant at the level of 0.01.
physiology scores did not differ significantly, there was a clearly discernible trend toward a higher increase of knowledge when students were part of the LMUdle sample group.

Figure 6 shows a graph of the difference of the difficulty index (see Test analysis) between the pre- and posttest items of both LMUdle and Traditional sample groups. This difference can be interpreted as a measure of the knowledge increase. Students of the LMUdle group improved their knowledge more than students of the Traditional group in 13 items, 10 of which differed by >10%. Differences for the five items for which students in the Traditional group scored better ranged from 2% to 7%. A particular distribution of the knowledge increase with regard to subjects (physiology or physics) has not been previously detected.

Physiology knowledge, physics knowledge, and transfer. To examine relations between the students’ specific knowledge of each discipline and the ability to transfer it between fields, a structural equation model was built and verified with the aid of path analysis. The model contained the exogenous variable transfer ability as well as the two endogenous variables: physiology knowledge and physics knowledge. These three latent variables were measured with knowledge test items as observable indicators. Figure 7 shows the model with estimated path coefficients of the term 2011 group. The RSMEA of this model was ε = 0.045 and χ²/df = 1.641, both indicative of a close model fit. This structural model was confirmed by the term 2010 group and its values: χ²/df = 1.179 and ε = 0.025 (corrected P = 0.23). As the indicator variables of the term 2010 group did not follow a multivariate normal distribution, the P value was corrected as recommended by Bollen and Stine (3).

The correlations between the test scores for physiology, physics, and transfer are shown in Table 5 and indicated medium effect sizes (7). The squared correlation coefficient (r²) describes the influence of one variable’s variation on the variation of another variable and can be interpreted as a percentage.

Navigation Behavior

To analyze the navigation behavior of the students, the tracked navigation steps were counted. For this analysis, only students with at least 10 navigation steps were considered for further analysis. Their total number of navigation steps was N = 2,986.

Usage of different types of navigation. Course overview navigation was used most frequently (45%), followed by the navigation menu (31%). The concept map-based navigation was used for 18% of navigation steps, whereas 6% of the navigation steps were made by direct guidance. As text links are sparse, this type of navigation was rarely used.

Interdisciplinary navigation within the LMUdle course was only possible using course overview or concept map-based
navigation. Table 6 shows the ratio of interdisciplinary to inner disciplinary navigation steps for course overview and concept map-based navigation alone as well as all types of navigation together.

**Use of learning objects.** When the number of navigation steps to learning objects made using course overview navigation was quantified, the following features became apparent:

- The first two learning objects of the course overview were visited significantly more often than other learning objects.
- The first two learning objects of each section were visited more often than other learning objects.
- The subject physics 1 (electric circuits without capacitor) was visited more often than physics 2 (electric circuits with capacitor and signals), which itself was used more often than the physiology portion.
- Indented links of the course overview were used less often than other learning objects.

**Types of learning object.** The LMUdle course contained text pages, self-assessments, interactive elements, experiment descriptions, animations, videos and podcasts, PDF files, and clinical applications. Table 7 shows the number of visits to the different types of learning objects. To allow comparisons between groups of learning objects, the mean was calculated by dividing the sum of visits by the number of objects of the respective type. The mean for self-assessment was clearly highest, followed by text pages and then videos and podcasts.

**Subjects.** Numbers of visits to each subject within the LMUdle course are shown in Table 8. The learning objects in physics were visited clearly more often than the learning objects in physiology.

**Structure of navigation.** Global navigation. Table 9 shows the different types of navigation, their \( \text{lm} \) values, and the number of visited learning objects. The concept map-based navigation clearly possessed the highest value of \( \text{lm} \), followed by course overview navigation. The number of learning objects visited via concept map-based navigation was small compared with the other types of navigation. The smaller number of learning objects seemed to be a consequence of the fact that the number of navigation steps made with the concept map was distinctly lower than with other types of navigation.

**Networks of different navigation kinds.** Closer analysis of the navigation networks using the type of navigation and link weight as filters revealed the networks shown in Fig. 8. These networks illustrated all transitions observed between any two learning objects. Link weight is the number of transition steps to learning objects. Link weight is the number of transition between any two objects. This measure is direction sensitive. Because the overall number of navigation steps differed between the different types of navigation, their link weight was also expected to vary. To correct for this effect, link weights are given as relative link weights, which have been scaled proportional to the total number of navigation steps observed for a particular type of navigation.

Strikingly, use of the navigation menu was concomitant with the absence of linkage between the subjects. There was no interdisciplinary navigation, as shown in the networks for course overview or concept map-based navigation. In contrast, physics nodes (blue and orange nodes) were often linked in a nonserial triangular manner, whereas physiology linkage (green nodes) was more serial (Fig. 8). As link weights were relatively high for this type of navigation, it was dominating the overall navigation network. The best interdisciplinary navigation was achieved by the use of concept map navigation, where physiology was embedded in between both of the physics courses.

### Student Satisfaction With the LMUdle Course

Student feedback relating to their satisfaction is shown in Table 10. Students rated the LMUdle course as facilitative in understanding contents, but they preferred traditional media, such as books and lecture notes. There was no clear message about the benefit of interactive elements, animations, self-assessments, or concept map-based navigation. A positive trend of having fun when using the LMUdle course was noted.

To learn about the reasons for minor participation in the research participation in the LMUdle course, ~100 participants of the term 2011 group were asked to answer some additional questions (cf. Table 10).
measures, and numbers of visited learning objects

<table>
<thead>
<tr>
<th>Type of Navigation</th>
<th>Specific Linkage Measure</th>
<th>Number of Visited Learning Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>0.27</td>
<td>81</td>
</tr>
<tr>
<td>Course overview</td>
<td>0.47</td>
<td>81</td>
</tr>
<tr>
<td>Navigation menu</td>
<td>0.31</td>
<td>81</td>
</tr>
<tr>
<td>Concept map based</td>
<td>0.68</td>
<td>67</td>
</tr>
</tbody>
</table>

Their answers showed that they did not doubt the quality or benefits of the course. Feedbacks on the free text fields offered that students would rather need more time to work with such additional learning materials and that they lacked a close relation between term assessments and the hypermedia course.

Learning Behavior

All pre- and posttest questionnaires of both terms were used to examine students’ learning preferences.

Used learning materials. Books and physics scripts were indicated to be the most intensively used, followed by own lecture notes and online materials outside the LMUdle course. Journal articles and the LMUdle course were rated as “minor use.”

Offered time to learn. A comparison of the time invested in learning showed that students in the LMUdle group spent significantly more time for self-learning than students in the traditional group (P = 0.001; see Table 11).

Efficiency of learning. The dependence of the students’ knowledge increase on time spent on learning is shown in Table 11. The results showed that students in the LMUdle group tended to perform better than students in the traditional group. This difference became significant for a learning time of >4 h/wk (P = 0.03). If learning efficiency is defined as knowledge increase per learning time, students in the LMUdle sample group learned more efficiently than students in the traditional group.

DISCUSSION

In previous work, we (26) addressed the interdisciplinary learning of physics and physiology within a second-year medical curriculum. That study focused on the design of addressee-specific face-to-face learning materials and demonstrated that their introduction had significant and large effects on knowledge and transfer capabilities of students.

In the present study, we transformed these learning materials into learning objects of a web- and hypermedia-based learning environment. A recent work (4) has listed the beneficial effects of such approaches on learning. The exact conditions, however, under which these occur still remain to be better defined (6, 10, 18, 24, 25). In addition, there is, to the best of our knowledge, no previous work that has specifically addressed how such systems influence the development of students’ transfer capabilities.

Participants of the web- and hypermedia-based LMUdle course presented and studied in this report showed significantly increased overall knowledge compared with a control group working with face-to-face materials only. The increase in students’ knowledge was analyzed by a comparison of pre- and posttest questionnaires (cf. APPENDIX). In agreement with a previous study (23), this confirms that the widely used open-source platform Moodle can be implemented as an effective web-based learning tool. Importantly, using the same methodological approach, we also showed a significant and medium-size positive effect on transfer capabilities. Thus, this particular feature of our previously designed face-to-face learning materials was successfully transferred to the web-based system.

Knowledge in physics and physiology as well as transfer capability are abstract concepts. As we attempted to measure these concepts using questionnaires, we wondered whether these data could be used to understand their relationships. We used Amos path analysis to generate a model, which, according to recommended quality criteria, seemed reliable. Moreover, the same model was confirmed for two different and independent groups of students.

This analysis showed a great influence of students’ transfer ability on their knowledge of physiology and physics. The correlations between knowledge in single disciplines and transfer ability were highly significant, with a medium effect size. It seems likely that transfer might measure more active and more involved learning. In this sense, our model presumably confirms previous experiences on the value of these types of learning. Even if structural equation modeling has to be carefully approached and interpreted, our model suggests the existence of separable domains of single discipline knowledge and transfer. It reveals their interdependence and argues for integration into curricula of both inner disciplinary and interdisciplinary learning.

Web- and hypermedia-based approaches allow organization of far larger amounts of information than is reasonably possible on paper. Principally, however, both approaches suffer from the same problem, i.e., students getting lost, being unable to learn and find their way. A number of studies (5, 14, 19) have addressed related issues, such as the benefits of direct guidance for particular groups of students or the advantages of allowing choice between different navigation styles. We reasoned that map-like orientation might be efficient, acceptable, and useful for large groups of users (for a previous work on concept map-based navigation, see Ref. 19). Many students are used to maps implemented in their computer games. In contrast to these often detailed and complex maps made up of a huge number of different visual elements, we designed a simple concept map-based semantic web-like orientation structure. This tool was implemented as a plugin for Moodle. It comprises a number of features, which make its use flexible and convenient for learners as well as providers of learning structure and content (see MATERIALS AND METHODS and RESULTS).

Concept-map based navigation was available to the users in parallel to course overview navigation and the navigation menu as they are available in standard implementations of Moodle. In addition, direct guidance was offered. Students were free to choose among these navigation styles. As students were well acquainted with the appearance and use of course overview and navigation menu from previous Moodle experience, it was not surprising that ~75% of all navigation steps fell into these categories. Analysis of navigation behavior, however, revealed that concept map-based navigation supports interdisciplinary navigation. Whereas the proportion of interdisciplinary to inner disciplinary navigation was similar for all pairs of subjects when all navigation or course overview navigation were considered, the same measure for concept map-based navigation...
differed remarkably. Students navigated more meaningfully with regard to related contents when they used concept map-based navigation. Although this explanation cannot be proven by our data, this effect is presumably due to the preordered linear structure of the course overview menu. This hypothesis is supported by the effects of position and layout of an item in the course overview menu on the frequency of its usage. The much higher $lm$ value of concept map-based navigation compared with all other types of navigation is indicative of more global navigation and presumably at least in part due to enhanced interdisciplinary navigation. Additional support of this hypothesis comes from an inspection of navigation networks. With increasing relative linkage weight, navigation networks for course overview navigation and navigation menu navigation decompose into monodisciplinary subnets much faster than networks for concept map-based navigation. We are aware that future research has to further address the robustness and significance of the novel analytic tools ($lm$ and navigation network) introduced here.

With respect to preferences of types of learning objects, our study largely confirms previous work (29). Self-assessments were most frequented, followed by text pages and videos. Intermediate use was observed for animations and interactive elements, whereas descriptions of experiments, PDF files, and

![Fig. 8. Navigation networks for the different types of navigation. Relative link weights ($l$) of the three networks of each column were similar. Thus, the different navigation types can be compared column by column. Raw values of $l$ were as follows: $l \cong 6$ (A), $l \cong 11$ (B), $l \cong 17$ (C), $l \cong 2$ (D), $l \cong 5$ (E), $l \cong 7$ (F), $l \cong 2$ (G), $l \cong 3$ (H), $l \cong 5$ (I), $l \cong 1$ (J), $l \cong 2$ (K), and $l \cong 3$ (L).]
clinical applications were least visited. Why physics objects were more frequently used remains unclear. This might in part be due to the negative attitude toward physics of the average student of medicine.

Students of the LMUdle course group spent, on average, significantly more time on self-learning and achieved higher increases of knowledge than control participants. In fact, LMUdle course participants learned more efficiently, as their knowledge increase was higher than that achieved by control participants. In fact, students of the LMUdle course group spent, on average, significantly more time on self-learning and achieved higher increases of knowledge than control participants. In fact, LMUdle course participants learned more efficiently, as their knowledge increase was higher than that achieved by control students with the same self-learning commitment. If students learned >4 h/wk, this trend became a significant difference.

Changing working curricula by the integration of novel contents and web-based approaches to make them available is difficult. Most often, it is not possible to introduce large changes immediately as obligatory features. Teachers and those responsible for teaching first need to be convinced of the benefits of the new approach. Therefore, innovations come as an addition to a curriculum, which is already well filled, as was the case for our LMUdle course. As previously observed by others (24), the average student will consider use of such additional nonobligatory material a luxury not required to pass course exams (2). The most rational approach to this dilemma seems to be a piece-by-piece introduction of novel elements accompanied by the replacement of old structures.

Our data showed that web-based hypermedia learning environments built around Moodle are very useful with respect to enhancing interdisciplinary learning outcomes. To fully exploit the attractiveness of such systems, concept map-based navigation, adaptivity, and full integration into a curriculum are required.

**APPENDIX**

Knowledge Test

**Question 1 (physics).** Examine the diagram showing electrical potentials (Fig. 9). Locations with the same electrical potential are shown as dashed lines. An electrical charge is moved from point A to point B.

Which statement about the absolute electrical work performed by the charge transport is correct?

* A. The most work is performed in situation II.
* B. The most work is performed in situation III.
* C. The performed work is equal in situations I and II but less than in situation III.
* D. The work performed in all three situations is equal.
* E. I don’t know.

**Question 2 (transfer).** To assess the equilibrium potential ($U_\text{eq}$) of a cell membrane, the following Nernst equation can be used to compute the electrical work performed per unit charge (where $R$ is the gas constant, $T$ is temperature, $z$ is charge, $F$ is Faraday’s constant, $c_i$ is the ion concentration outside the cell, and $c_o$ is the ion concentration inside the cell):

$$U_\text{eq} = \frac{zF}{c_o - c_i}$$

**Table 10. Students’ satisfaction with the LMUdle course and reasons for minor participation**

<table>
<thead>
<tr>
<th>Question</th>
<th>Number of Students</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The concept map-based navigation did facilitate my understanding of the topics of the practical courses.</td>
<td>22</td>
<td>3.14</td>
<td>0.89</td>
</tr>
<tr>
<td>2. Self-assessments helped me to monitor my knowledge status.</td>
<td>22</td>
<td>2.86</td>
<td>1.36</td>
</tr>
<tr>
<td>3. Animations facilitate my learning very much.</td>
<td>22</td>
<td>2.77</td>
<td>1.17</td>
</tr>
<tr>
<td>4. Interactive elements facilitate my learning very much.</td>
<td>22</td>
<td>3.05</td>
<td>1.17</td>
</tr>
<tr>
<td>5. The use of the LMUdle course was a lot of fun.</td>
<td>23</td>
<td>2.78</td>
<td>1.06</td>
</tr>
<tr>
<td>6. The use of the LMUdle course did not facilitate my understanding of the practical courses topics.</td>
<td>25</td>
<td>4.44</td>
<td>0.80</td>
</tr>
<tr>
<td>7. I prefer online learning materials like the LMUdle course rather than traditional media (books, lecture notes, etc.).</td>
<td>28</td>
<td>4.55</td>
<td>0.95</td>
</tr>
<tr>
<td>8. I don’t like the LMUdle platform at all.</td>
<td>84</td>
<td>3.71</td>
<td>1.10</td>
</tr>
<tr>
<td>9. I don’t like it to learn with computer.</td>
<td>91</td>
<td>2.84</td>
<td>1.43</td>
</tr>
<tr>
<td>10. I think that the LMUdle course is unnecessary.</td>
<td>79</td>
<td>3.96</td>
<td>0.98</td>
</tr>
<tr>
<td>11. I don’t have time to use learning materials like the LMUdle course.</td>
<td>84</td>
<td>2.69</td>
<td>1.19</td>
</tr>
<tr>
<td>12. For me the LMUdle course is very confusing.</td>
<td>45</td>
<td>3.51</td>
<td>1.27</td>
</tr>
<tr>
<td>13. For me there is no need to use the LMUdle course.</td>
<td>57</td>
<td>3.91</td>
<td>0.98</td>
</tr>
<tr>
<td>14. I mistrust the quality of LMUdle course contents.</td>
<td>54</td>
<td>4.35</td>
<td>0.81</td>
</tr>
<tr>
<td>15. I didn’t hear about the LMUdle course.</td>
<td>61</td>
<td>4.33</td>
<td>1.25</td>
</tr>
<tr>
<td>16. I was advised against the usage of the LMUdle course.</td>
<td>56</td>
<td>4.75</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Questions were scored on a scale of 1–5, where 1 = strongly agree and 5 = strongly disagree. Original questions were translated from German to English.

**Table 11. Knowledge increases with respect to time spent on learning**

<table>
<thead>
<tr>
<th>Time</th>
<th>LMUdle Group Mean</th>
<th>SD</th>
<th>Traditional Group Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 h/wk</td>
<td>n.a.</td>
<td>n.a.</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Between 1 and 2 h/wk</td>
<td>5.0</td>
<td>2.0</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Between 2 and 4 h/wk</td>
<td>4.8</td>
<td>2.6</td>
<td>3.6</td>
<td>2.5</td>
</tr>
<tr>
<td>&gt;4 h/wk</td>
<td>4.1</td>
<td>2.8</td>
<td>2.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

N/A, not applicable.
Which arithmetic operation has to be done with the Nernst equation for this purpose?
A. None; the voltage represents the electrical work performed per charge.
B. Division by the total charge of the moved ions.
C. Multiplication with the total charge of moved ions.
D. Multiplication with the inverse of the membrane resistance.
E. I don’t know.

Question 3 (physiology). One important characteristic for describing excitable cells is the membrane potential. Under physiological conditions, which sort of ion contributes most to generating the membrane potential?
A. The sort of ion with the highest intracellular concentration.
B. The sort of ion for which the membrane conductance is highest.
C. The sort of ion with the highest valence.
D. The sort of ion with the highest equilibrium potential.
E. I don’t know.

Question 4 (physics). Which of the current-voltage curves (shown in Fig. 10) shows the highest ohmic resistance?
A. Curve 1
B. Curve 2
C. Curve 3
D. Curve 4
E. I don’t know.

Question 5 (transfer). What is the qualitative relationship between the membrane potential and the number of ions per second moving through an ion channel, given that the channel conductance remains constant?
A. Linear
B. Quadratic
C. Exponential
D. Logarithmic
E. I don’t know.

Question 6 (physiology). Please complete the following sentence: A typical sodium-potassium pump _______.
A. is involved in the maintenance of the resting membrane potential.
B. is inactivated during the rising phase of the action potential.
C. results in the potassium concentration in the cell being higher than that outside the cell.
D. moves particular sodium ions into the cell.

Fig. 11. Question 9 of the knowledge test. $I$, current (in A); $U$, voltage (in V).

$$U_m = \frac{R \times T}{z \times F} \times \ln \frac{C_2}{C_1}$$

$U_m$ is the Nernst potential.

Fig. 10. Question 4 of the knowledge test. $I$, current (in A); $U$, voltage (in V).

Fig. 12. Question 12 of the knowledge test.

E. I don’t know.

Question 7 (physiology). Which statement about the refractory period is correct?
A. During the refractory period, no action potential can be elicited.
B. The duration of the refractory period is 50–100 ms, depending on the cell type.
C. Voltage-gated potassium channels are responsible for the refractory period.
D. The refractory period ensures that the action potential moves away from stimulus location.
E. I don’t know.

Question 8 (transfer). Assume that 70 identical ion channels in a membrane open at exactly the same time. Which of the following statements is true?
A. The membrane potential is equal to the sum of the potentials across all individual ion channels.
B. The membrane potential is equal to the potential across one individual ion channel.
C. The membrane resistance is equal to the sum of the resistances of all individual ion channels.
D. The membrane resistance is equal to the sum of the inverses of all individual ion channel resistances.
E. I don’t know.

Question 9 (physiology). Compare two electric circuits, circuits A and B, with identical resistances ($R$; Fig. 11). The voltage ($U$) of the direct current voltage source is the same in both circuits. Which of the following statements is true?
A. The total electrical current in circuit A is twice as high as that in circuit B.
B. The total electrical current in circuit A is as high as in circuit B.
C. The total electrical current in circuit A is half of that in circuit B.
D. The total electrical current in circuit A is one quarter of that in circuit B.

Fig. 13. Question 16 of the knowledge test. $U$, voltage; $I$, current; $C$, capacitance; $R$, resistance.
E. I don’t know.

**Question 10 (physics).** How does the resistance of an electric conductor change if both its length and cross-sectional area are doubled?
A. The electric resistance is four times higher than before.
B. The electric resistance is two times higher than before.
C. The electric resistance is as high as before.
D. The electric resistance is half of that before.
E. I don’t know.

**Question 11 (transfer).** Squid axon membranes have a higher electrical conductance than vertebrate axon membranes. What causes this difference?
A. Squid axons are longer than vertebrate axons.
B. Squid axons have a greater cross-sectional area than vertebrate axons.
C. Squid axons have a thicker membrane than vertebrate axons.
D. Squid axon membranes have a higher electrical conductance than vertebrate axons.
E. I don’t know.

**Question 12 (physiology).** Consider an example circuit (Fig. 13). Examine the diagram showing the time constant.
A. The underlying stimulus in sections A–C has the same amplitude.
B. The underlying stimulus in section B has the same amplitude as that in section C and a higher amplitude than that in section A.
C. The underlying stimulus in section B has a higher amplitude than that in section A and a lower amplitude than that in section C.
D. The underlying stimulus in section B has a higher amplitude than that in section C and a lower amplitude than that in section A.
E. I don’t know.

**Question 13 (physics).** How does the capacity of a parallel capacitor change if the surface area and the distance separating its plates are doubled?
A. Its capacity is as half as before.
B. Its capacity is as high as before.
C. Its capacity is two times higher than before.
D. Its capacity is four times higher than before.
E. I don’t know.

**Question 14 (transfer).** How would the time required reach threshold change if both the stimulus duration and strength are constant, but the thickness of the membrane is halved and its surface area doubled?
A. It would be halved.
B. It would stay the same.
C. It would be doubled.
D. It would be quadrupled.
E. I don’t know.

**Question 15 (physiology).** Which statement about stimulating conduction along myelinated axons sheathed in myelin is true?
A. The shorter the internodes, the lower the conduction.
B. The shorter the internodes, the higher the action potential amplitude.
C. The thinner the nerve fiber, the higher the conduction velocity.
D. The lower the tissue temperature, the higher the conduction velocity.
E. I don’t know.

**Question 16 (physics).** Consider an example circuit (Fig. 13). Which parameters determine the time constant in the circuit above?
A. Resistance and voltage
B. Capacity and current
C. Voltage and current
D. Capacity and resistance
E. I don’t know.

**Question 17 (transfer).** How could a cell membrane with an embedded ion channel be described using electrical components?
A. The ion channel as a resistance and the intracellular and extracellular compartments as capacitor plates.
B. The ion channel as a cylindrical capacitor and the intracellular and extracellular compartments as resistance.
C. The ion channel as a resistance and the membrane lipids as a capacitor.
D. The ion channel as a cylindrical capacitor and the lipid bilayer as an isolator.
E. I don’t know.

**Question 18 (physiology).** Which statement about voltage-gated sodium channels is true?
A. They inactivate with a high probability at the resting membrane potential.
B. They open only if the membrane potential is positive.
C. They inactivate with a high probability during longer depolarization.
D. They inactivate with a high probability during the afterhyperpolarization.
E. I don’t know.

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**DISCLOSURES**

No conflicts of interest, financial or otherwise, are declared by the author(s).

**AUTHOR CONTRIBUTIONS**

Author contributions: A.S., K.D., and M.M. conception and design of research; A.S. performed experiments; A.S. analyzed data; A.S. and M.M. interpreted results of experiments; A.S. prepared figures; A.S. drafted manuscript; A.S., K.D., and M.M. approved final version of manuscript; M.M. edited and revised manuscript.

**REFERENCES**