

Meet the Metaorganism: A web-based learning app for undergraduate and graduate biology students

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Abstract

Meet the Metaorganism is a web-based learning app that combines three fundamental biological concepts (coevolution, community dynamics, and immune system) with latest scientific findings using the metaorganism as a central case study. In a transdisciplinary team of scientists, information designers, programmers, science communicators, and educators, we conceptualized and developed the app according to the latest didactic and scientific findings and aimed at setting new standards in visual design, digital knowledge transfer, and online education. A content management system allows continuous integration of new findings, which enables us to expand the app with the dynamics of the research field. Students can thus gain a close insight and connection to current research, and at the same time learn that knowledge is not static but grows dynamically. Especially in the realm of the easily accessible metaorganism research, visualization plays an essential role to keep complex processes understandable and memorable. *Meet the Metaorganism* is freely available online and can be accessed here: www.metaorganism.app.

KEYWORDS

digital learning, host–microbe interactions, metaorganism, microbiome education, online education, science education, visual science communication

INTRODUCTION: WE ARE NOT ALONE

In nature, there are no solitary organisms; all plants and animals are colonized by microorganisms. In humans, for example, more than half of all cells are not of human but of microbial origin.¹ This entity of a host and its associated microbes is an evolutionary and functional unit called metaorganism.² Because host–microbe interactions play a pivotal role in virtually every aspect of development, evolution, ecology, health, and disease,³ the urgency of microbiome research has increased significantly in the last decade. The underlying “metagenomic” methods have

created an unprecedented amount of information about the diversity and ecology of microbes in different host organisms. Many of these microbial species were previously unknown. Nowadays, millions of microbial genes are combined into lists collectively known as the microbiome.

To support the exploration and understanding of the metaorganism concept and the underlying host–microbiome data, we present a new learning app for biology bachelor and master students that introduces the topic in an interactive and engaging manner, with a strong emphasis on the use of visualizations. Visualization plays a critical role in

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conveying the complex and often invisible processes and systems in the life sciences, allowing for a deeper understanding of the relationships and interactions between the host and its microbes.

In a transdisciplinary team of scientists, information designers, programmers, science communicators, and educators, we conceptualized and developed the app according to the latest didactic and scientific findings and aimed at setting new standards in visual design, digital knowledge transfer, and online education. In addition to the latest research findings and insights, the app includes educational resources, such as scientist quotes, quizzes, a glossary, and further readings, which facilitate understanding of the complex interplay between the host and its microbes. The app is web-based and content management system (CMS) editable, allowing for a swift integration of new research findings as they become available—a distinct advantage over standard textbooks. *Meet the Metaorganism* is freely available online and can be accessed here: metaorganism.app.

Meet the Metaorganism introduces basic key biological concepts and underlying processes using the metaorganism as a central case study. In the context of a holistic understanding of higher education, the application goes beyond the research-based, academic education of students and promotes self-directed learning that inspires and reinforces enthusiasm for biology. The app demonstrates how research works at multiple levels. It features unique content and texts that are specially created for this learning tool and seamlessly integrated with interactive visualizations. The application is web-based, which means that it can be opened in any modern browser and can be used both for self-study and to accompany a seminar. The content can be easily printed as a PDF file for offline usage. Individual visualizations can be exported from the app to include them in presentations.

METHODS: PRODUCTION OF MEET THE METAORGANISM

The development process has passed several stages, which were carried out in an iterative and collaborative manner. First, we defined the needs of our target group by creating *user stories*. This phase was followed by a thorough literature review and workshops with biology professors and educational scientists to identify the scientific content and didactic concepts for the app. Next, the creation of a storyboard served as the basis for the development of the app's structure and design. We then implemented the app's functionalities and visual elements. Finally, we incorporated feedback from users and experts on the prototype and further developed the remaining contents.

Research, scientific content, and didactic concepts

To initiate the educational reconstruction process, it is crucial to start with a thorough examination of scientific content.⁴ This includes a qualitative content analysis of reliable sources, in our case of existing lectures for bachelor biology students. To ensure the accuracy and relevance of the content, we additionally engaged in discussions with

biology lecturers. Moreover, we ensured that our app covers the latest discoveries and research methodologies from ongoing studies. Specifically, we drew upon the Collaborative Research Centre CRC 1182 “Function and Origin of Metaorganisms,” which provided valuable examples for the app. Our next step was to evaluate the educational significance of the content and formulate clear and concise educational objectives. To achieve this, we collaborated with educational scientists (see Supplementary material for a list of the educational objectives).

Most important in such a project is to understand the needs and expectations of the user and the audience. We have taken *user stories* to analyze the needs of our target group, a technique used in agile software development to capture the needs that a user may have when interacting with a product or software.⁵ They typically follow the format “As a [type of user], I want [some goal or feature], so that [some reason or benefit].” By focusing on the user's perspective, developers can ensure that the app is designed with the user's needs in mind, and that the features and functionality of the app are tailored to meet those needs. Additionally, user stories can help to prioritize features and functionality, in order to ensure that the most important and useful features are developed first. We created our user stories based on workshops with students and lecturers (see additional material for complete set of user stories). Therefore, right from the beginning, we took the needs and goals of lecturers and students into account.

User experience design and prototype development

The underlying data and information for the learning app were enormously diverse. The challenge was to develop an overall visual language that was easy to understand and appealing, while still maintaining scientific accuracy. We created a storyboard, which served as the basis for the development of the app's structure and design. Analogous to semantics and syntax in the written language, a consistent visual language is essential for a cohesive narrative. One important element in visual science communication is a *key visual*, that leads through the application. For this learning app, we defined two main key visuals: (i) the interface between host and microbiota as spatial information, and (ii) flowcharts, as the metaorganism is characterized by interactions and dependencies. Additionally, a set of visual design principles was used to create an engaging and accessible learning tool. We used a schematic and reduced design to highlight contents showing theoretical background and general principles, and a more vivid, naturalistic design with high-quality 3D renderings for applied science.

Testing and validation of a prototype

We programmed a prototype of *Meet the Metaorganism* containing one of the three chapters (Coevolution) and its full navigational structure and tested it in three steps: First, the technical and functional usability was tested internally. Second, the prototype was prevalidated in an open interview and with an online questionnaire on cognitive (interactivity, engagement, content, learner guidance) and affective (relevance,

Meet the Metaorganism: Development & Production

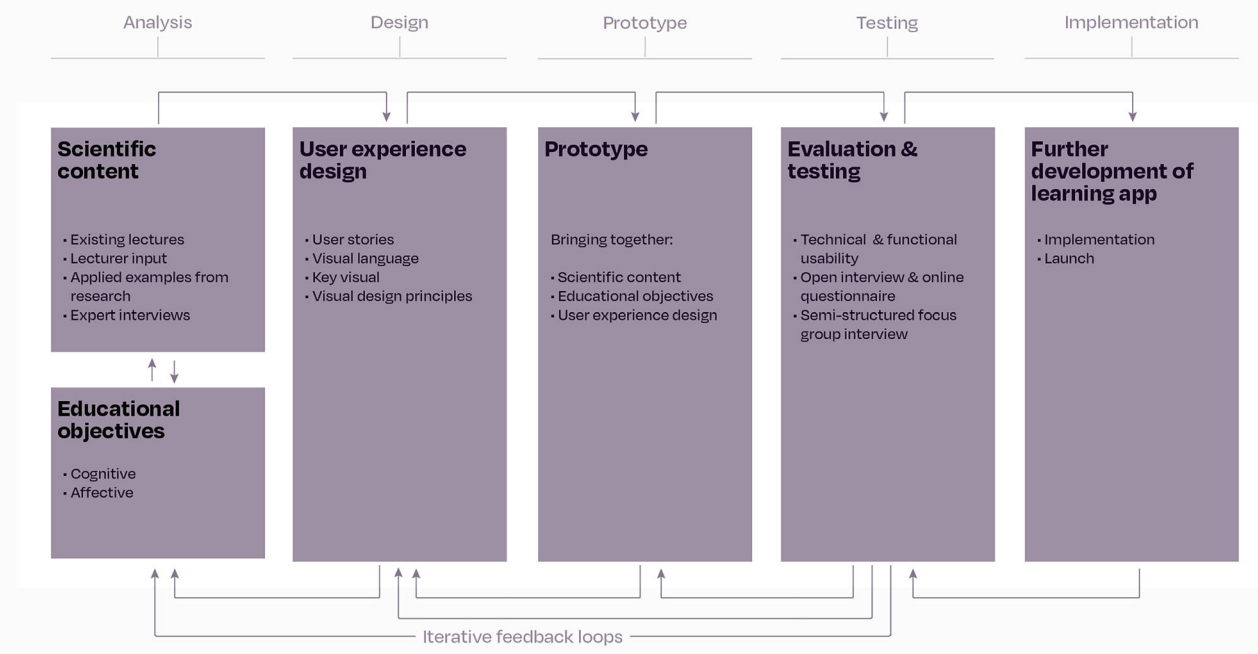


FIGURE 1 Developmental process stages with iterative feedback loops.

satisfaction) factors with bachelor and PhD students ($n = 4$) from biology. Third, after integrating the feedback from the prevalidation, the prototype was field tested and evaluated with semi-structured focus group interviews with master students in biology ($n = 15$) and a bachelor's course ($n = 9$). The focus group interviews were conducted in a video conference setting with typically 5–10 participants and were facilitated by a moderator who guided the discussion. The moderator asked open-ended questions to encourage participants to share their experiences, opinions, and suggestions related to the new learning app. The focus group interviews were both audio-recorded and documented with notes to capture all the responses and discussions. The recordings and notes were later analyzed to identify themes, patterns, and insights related to students' experiences and perceptions of the learning app.

The iterative nature of the developmental process allowed us to refine the app's functionalities and design based on feedback from different perspectives. All the insights and feedback served as a baseline to implement the other two chapters accordingly. The scientific content was reviewed and corrected in several iterations with the help of a scientific board to reach scientific accuracy.

RESULTS: MEET THE METAORGANISM

The transdisciplinary collaboration allowed us to create a learning app that combines scientifically accurate content with state-of-the-art visualization and design, following current didactic concepts for knowledge transfer.

Evaluation results

The learning app underwent multiple rounds of testing and evaluation, which yielded insightful feedback from students of different academic levels. After the first internal check of technical and functional usability, the students from the prevalidation found the app attractive and enjoyed the interactive features. However, the font size was criticized as too small, and more interactive graphics were requested. In the third round of evaluation, master and bachelor students in biology tested the app with one chapter (Coevolution), and we conducted semi-structured focus group interviews with the students and one lecturer. The feedback was unanimously positive. The app's visual design was again approved for its attractiveness, while the interactive visualizations were found to enhance students' understanding of the metaorganism concept. Some of the visualizations, however, were perceived as unfamiliar or decorative, highlighting the need for more precise investigation of multimedia effects in future studies. Students found the app easy to navigate, with clear and concise explanations of key concepts related to the metaorganism. Most of the content was deemed appropriate for both bachelor (in a guided way) and master students (by self-studying), with quizzes being particularly well perceived as a means of reinforcing learning and assessing understanding. The feedback obtained during testing and evaluation was incorporated into the app's design and layout, with changes made to improve readability, enhance interactivity, and emphasize the fundamental and transferable nature of biological concepts (Figure 1).

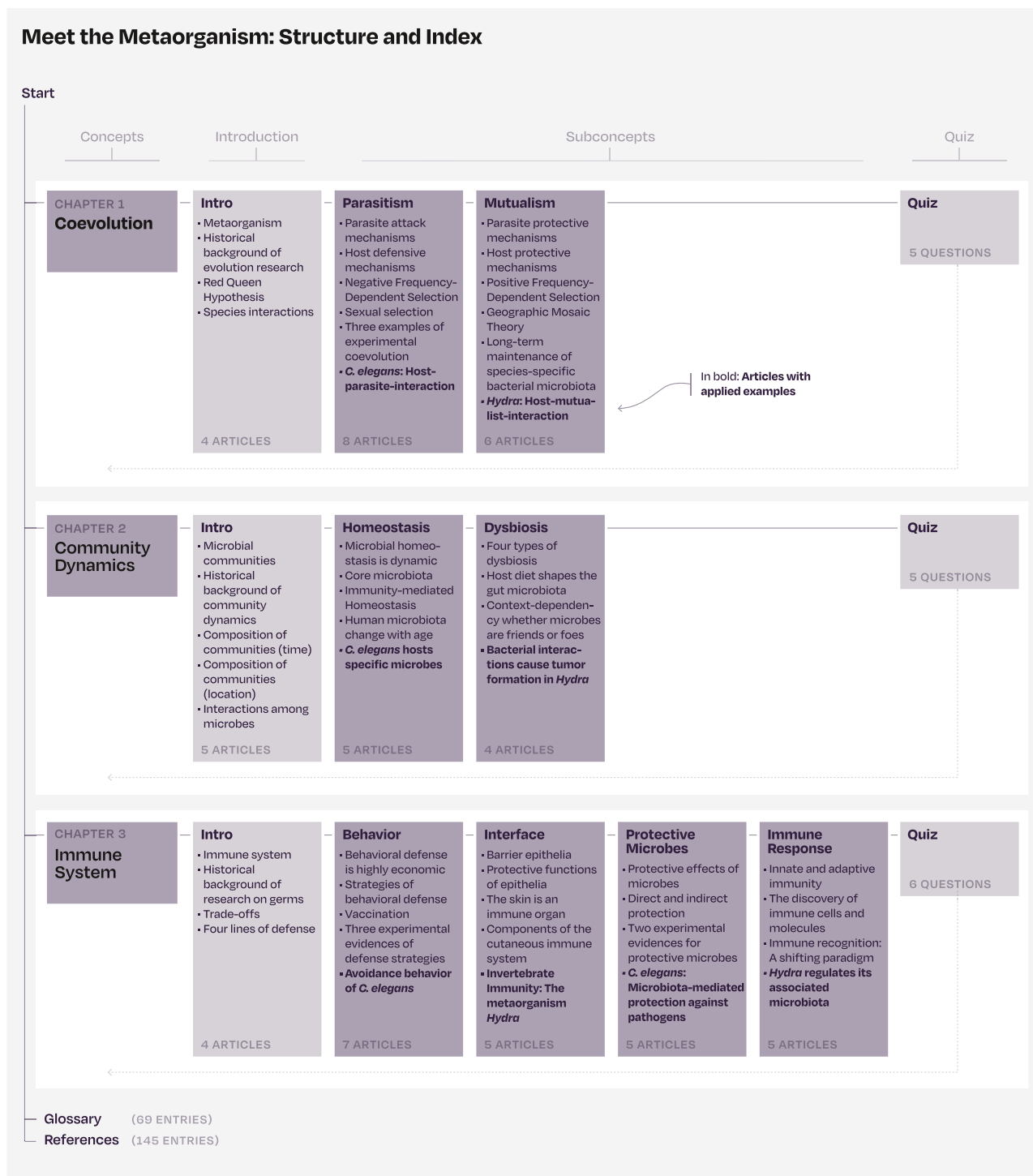


FIGURE 2 Structure and content of Meet the Metaorganism.

Structural results

Using narration to structure the scientific content can facilitate the understanding of scientific knowledge, as storytelling lies in the nature of humankind and triggers neuronal structures in the brain that help memorizing.⁶ To convey biological processes in general and the origin

and function of metaorganisms in particular, the learning app structures them into three different core concepts, that translate into three chapters within the learning app (Figure 2). The core concepts summarize host-microorganism interactions from different perspectives, spanning from brief timeframes and molecular scales to extended periods and population levels. However, science is an ever-evolving

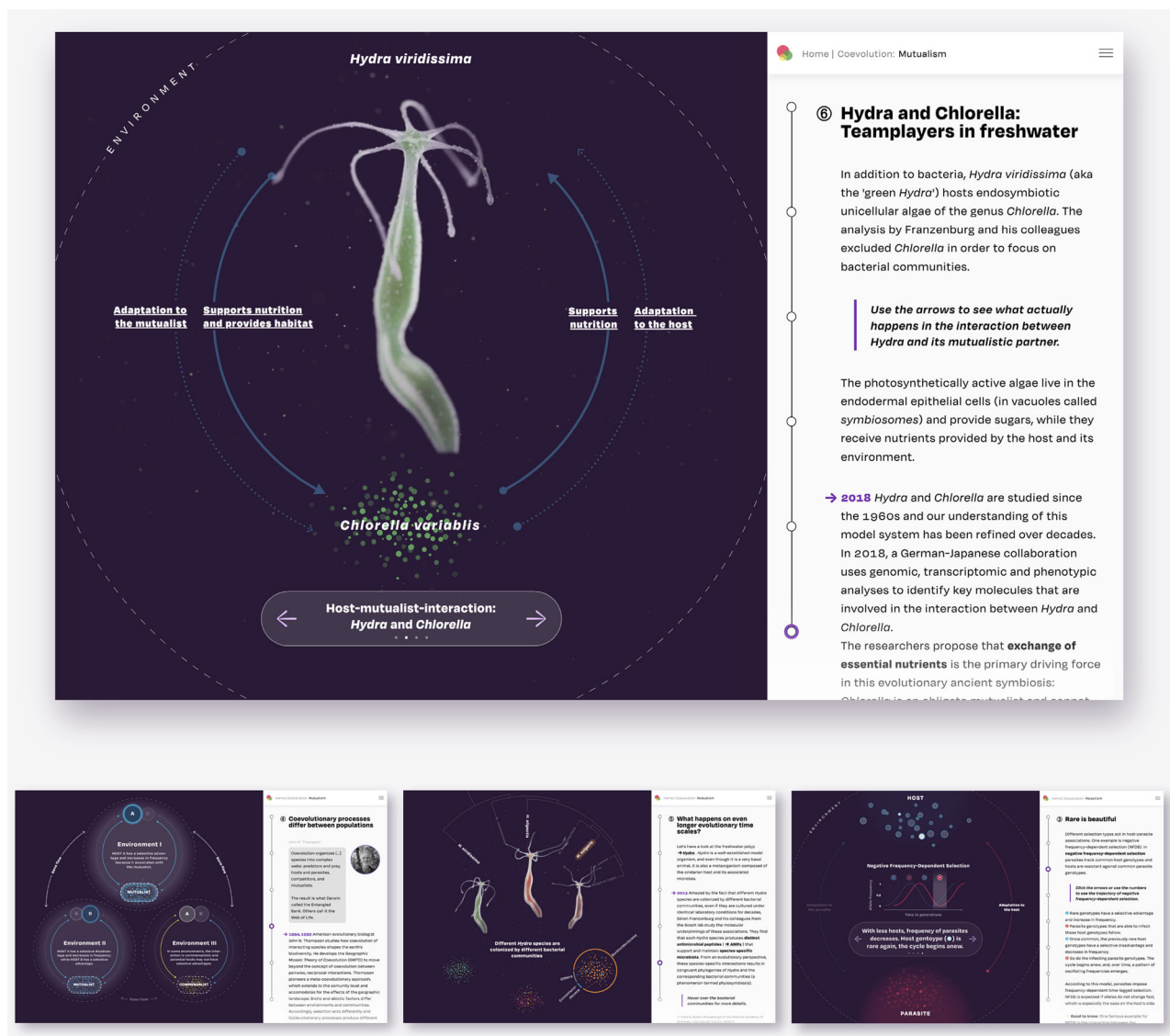


FIGURE 3 Exemplary view of different screens. Top screen: mutualistic interaction between *Hydra* host and its microorganisms. In a step-by-step explanation, the beneficial interaction and its underlying processes are explained. Down: examples of different designs: flowcharts explaining concepts and applied science examples.

field: with knowledge becoming increasingly complex over time and paradigms undergoing complete shifts. Understanding the scientific process is, therefore, a crucial objective in science education, often referred to as the *nature of science*.⁷ We aimed to integrate this dynamic nature of science into the design of our learning app. Therefore, all content is built up step by step, following a timeline of metaorganism research. This approach has the advantage that students acquire the subject-specific expertise as well as understand how scientific knowledge is generated.

The first chapter *Coevolution* covers interactions that are of long duration and happen at the species level. The second chapter *Community Dynamics* shows the interactions between host and associated microbes that are of shorter duration and happen at the individual or population level. The third chapter *Immune System* covers interactions

that are of short duration at high (molecular) resolution. The three concepts can be accessed independently of each other.

In each chapter, the screen is split into two sections: a visualization and a timeline containing written content. To prevent long flowing texts, we broke up the timeline with facts worth knowing ("good to know") and quotes from researchers in the field (Figure 3). At the end of each paragraph, all relevant citations supporting the text are linked to the respective original research articles. This promotes the method of scientific working, enhances transparency, and increases trustworthiness. Within the text, words that might be rather difficult to understand are linked to a glossary and hovering over them provides a short explanation. Quizzes at the end of each chapter encourage users to apply newly acquired knowledge, and feedback on results motivates the user to either review the chapter or progress to the next one.

The visualizations of flowcharts and control loops are of great importance in the application. They take up two-thirds of the design area. These visualizations serve a dual purpose: First, they remind the user of the model organisms through their repeated and highly naturalistic representation, which also anchors them visually.⁸ Second, the consistent representation style in the schemes triggers connections between contents and they become more accessible to the user. The step-by-step structure directly visualizes scientific developments and the growing knowledge in research. To provide an applied counterpart to the more theoretical, conceptual aspects of the content, each subchapter concludes with the incorporation of two model organisms. These models, the polyp *Hydra spp.* and the nematode *Caenorhabditis elegans*, are used to illustrate (i) the relevance of model organisms in science, and (ii) the importance of experimental research in obtaining scientific insights.

CONCLUSIONS

The app *Meet the Metaorganism* offers an innovative and valuable resource to students, promoting a deeper understanding of the metaorganism and inspiring curiosity in this rapidly evolving field of study.

- (i) *Interactive and visual learning apps*: The human working memory has only a limited performance capacity (Sweller, 1988⁹). Therefore, combining words with visuals facilitates learning by enabling learners to construct more efficient mental representations of the topic.¹⁰ Adding interactivity as an educational method allows to explore different layers of information subsequently, thus reducing complexity. Furthermore, the use of interactive visualizations adds another layer of engagement, facilitating in-depth exploration and understanding of the topic.¹¹ With the app *Meet the Metaorganism*, we utilize a visual and interactive approach in order to enhance visual memory and support learning. Especially in the realm of phenomena, which cannot be seen by the human eye (e.g., microbial interactions), visualization plays a key role to make complex processes accessible, comprehensible, and memorable.
- (ii) *Insights into transdisciplinary collaboration*: In this project, we brought together scientists, programmers, information designers, science communicators, educational scientists, biology students, and lecturers. Such collaboration across disciplines has the potential to greatly enhance both science communication and higher education, resulting in more accessible, engaging, and effective products.¹² The applied transdisciplinary approach was key for producing this dynamic learning app for biology students, featuring unique content and interactive visualizations, emphasizing the nature of science. With the help of this app, we hope to provide a valuable tool for students to deepen their understanding of the metaorganism and to encourage interest in this exciting and rapidly advancing research field.

AUTHOR CONTRIBUTIONS

Susanne H. Landis, Agnes Piecyk, Manuel Reitz, Carolin Enzingmüller, Hinrich Schulenburg, Thomas Bosch, Katja Dierking, and Tom Duscher contributed to the writing of the manuscript. Susanne H. Landis, Agnes Piecyk, Manuel Reitz, Carolin Enzingmüller, Hinrich Schulenburg, Thomas Bosch, Katja Dierking, Peter Deines, Jonas Hunfeld-Häutle, Konrad Rappaport, and Tom Duscher contributed to the concept, development, testing, and production of the learning app.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the supplementary material of this article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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