Carinthia II

Nature Tech

Part 3

Published since 1811
216th Year of Carinthia

Volume 3

Issue 1

2026 Verlag des Naturwissenschaftlichen Vereins für Kärnten

Interdisciplinary approaches exploring the connection between biology and technology through slime mold simulation

Kristina Wogatai, Viviane Elmenreich, Anastasia Pulvermacher, Wilfried Elmenreich

ABSTRACT

Slime molds are fascinating organisms that, despite their name, are not fungi but amoeboid protists. Among them, the plasmodial slime mold *Physarum polycephalum* forms a multinucleate syncytium, known as the plasmodium, through repeated nuclear divisions without cytokinesis. In this phase, the organism appears as a viscous network-like mass containing millions of nuclei and is capable of solving complex tasks, such as navigating mazes, through self-organized behavior. Additionally, *P. polycephalum* is easy to culture and handle, making it an ideal model organism for studying self-organization, adaptive behavior, and biological network formation. The Smart Grids research group in the Department of Networked and Embedded Systems (NES) at the University of Klagenfurt conducts research involving slime molds. Specifically, the group investigates the potential of self-organizing applications in energy networks.

In cooperation with the Austrian Research Promotion Agency (FFG), the Faculty of Technical Sciences at the University of Klagenfurt offers Austrian students aged 15 and older the opportunity to gain insight into university-level research through a four-week summer internship. The project "Experiments with Slime Molds" was offered for the second time in 2024 by the Smart Grids research group. This interdisciplinary project allows participants to explore the intersection of biology and computer science. The internship offers participants the chance to explore the interfaces between biology, computer science, and mathematics. It is especially aimed at students interested in biological systems, the application of mathematical models, and the development and use of software tools for simulating natural phenomena. The interns begin by cultivating slime molds in Petri dishes and then simulate their behavior using SISMO (Simulation of Slime Molds), a tool developed by the Smart Grids group.

This article explores how biology and technology were combined in a four-week internship program and provides insights into the individual experiments conducted. A central element is the report by intern Viviane Elmenreich, who shares her experiences from the 2024 IT internship at the University of Klagenfurt. The focus of the internship was on biological experiments with the slime mold *P. polycephalum*, including the cultivation and reactivation of sclerotia, analysis of information processing within the plasmodium, and observations of behavioral and color response to stimuli. These experiments were complemented by technical components, such as programming a Raspberry Pi to automate time lapse photography and using the simulation tool SISMO to model slime mold behavior. The results demonstrated that slime molds are capable of absorbing information from their environment, processing dyes from food sources, and finding efficient paths to nutrients, both in physical experiments and in simulated environments. Furthermore, the combination of hands-on and digital approaches enabled deeper insights into the principles of biological self-organization. The internship not only contributed to the development and refinement of the SISMO simulation tool but also played a key role in enhancing the scientific education of the participants. The students gained valuable skills in experimental biology, programming, documentation, media production, and interdisciplinary research. These experiences fostered scientific thinking and also served as a strategic investment in talent development and in strengthening the University of Klagenfurt's position as an innovative research institution.

KEYWORDS

- Biology
- Slime Molds
- Simulation
- Self-Organizing Systems
- Interdisciplinarity
- Nature-based Algorithm
- *Physarum polycephalum*
- Science Communication
- IT Internship

Interdisziplinäre Ansätze zur Erforschung der Verbindung zwischen Biologie und Technologie durch Schleimpilzsimulation

ZUSAMMENFASSUNG

Schleimpilze sind faszinierende Organismen, die trotz ihres Namens keine Pilze, sondern amöboide Protisten sind. Unter ihnen bildet der plasmodiale Schleimpilz *Physarum polycephalum* durch wiederholte Kernteilungen ohne Cytokinese ein vielkerniges Synzytium, das sogenannte Plasmodium. In dieser Phase erscheint der Organismus als zähflüssige, netzwerkartige Masse mit Millionen von Zellkernen und ist in der Lage, durch selbstorganisiertes Verhalten komplexe Aufgaben zu lösen, beispielsweise das Navigieren durch Labyrinthe. Darüber hinaus lässt sich *P. polycephalum* einfach kultivieren und handhaben, wodurch es sich ideal als Modellorganismus für die Erforschung von Selbstorganisation, adaptivem Verhalten und biologischer

 DOI: 10.71911/cii-p3-nt-2026311

Netzwerkbildung eignet. Auch die Forschungsgruppe Smart Grids des Instituts für Vernetzte und Eingebettete Systeme (NES) an der Universität Klagenfurt beschäftigt sich mit Forschung rund um Schleimpilze dieser Art. Konkret beschäftigt sich die Forschung in der Smart Grids Gruppe mit der Frage nach dem Potential selbstorganisierter Anwendungen in Energienetzen.

Die Fakultät für Technische Wissenschaften der Universität Klagenfurt bietet in Zusammenarbeit mit der Österreichischen Forschungsförderungsgesellschaft mbH (FFG) österreichischen Schülern und Schülerinnen ab 15 Jahren die Möglichkeit, im Rahmen eines 4-wöchigen Ferialpraktikums Einblicke in die Forschung an der Universität Klagenfurt zu erhalten. Das Projekt „Experimente mit Schleimpilzen" wurde 2024 zum zweiten Mal in der Forschungsgruppe Smart Grids angeboten. In diesem interdisziplinären Projekt beschäftigen sich die Praktikant:innen mit einer Kombination aus Biologie und Informatik. Sie arbeiten zunächst mit Schleimpilzen, die in Petrischalen kultiviert werden, und simulieren anschließend deren Verhalten mit dem in der Smart Grids Gruppe entwickelten Tool SISMO (Simulation of Slime Molds). Das Praktikum bietet den Teilnehmer:innen die Gelegenheit, die Schnittstellen zwischen Biologie, Informatik und Mathematik zu erkunden. Es richtet sich insbesondere an Schüler, die Interesse an biologischen Systemen, der Anwendung mathematischer Modelle und der Entwicklung sowie Anwendung von Softwaretools zur Simulation natürlicher Phänomene haben.

Dieser Artikel beleuchtet, wie in einem 4-wöchigen Praktikum Biologie und Technik miteinander vereint werden und gibt einen Einblick in die einzelnen Experimente. Ein weiterer zentraler Punkt ist ein Bericht der Ferialpraktikantin Viviane Elmenreich, die ihre Erfahrungen im IT-Ferialpraktikum 2024 teilt. Dabei werden nicht nur die praktischen Versuche mit dem Schleimpilz *P. polycephalum* dargestellt, sondern auch deren wissenschaftliche Bedeutung sowie die strategische Relevanz des Praktikums für die Universität Klagenfurt herausgearbeitet. Im Mittelpunkt des Praktikums standen biologische Experimente zur Kultivierung und Reaktivierung von Sklerotien, zur Informationsverarbeitung im Plasmodium sowie zur Färbung und Verhalten von Schleimpilzen. Diese Versuche wurden durch technische Komponenten ergänzt, etwa die Programmierung eines Raspberry Pi zur automatisierten Bildaufnahme und die Arbeit mit dem Simulationstool SISMO zur Modellierung von Schleimpilzverhalten. Die Ergebnisse zeigen, dass Schleimpilze in der Lage sind, Informationen über ihre Umgebung aufzunehmen, Farbstoffe zu verarbeiten und effiziente Wege zu Futterquellen zu finden, sowohl in der realen Umgebung als auch in simulierten Szenarien. Zudem wurde deutlich, wie sich Experimente und digitale Modellierung gegenseitig ergänzen können, um biologische Selbstorganisationsprozesse besser zu verstehen. Das Praktikum trug nicht nur zur Weiterentwicklung des Simulationstools SISMO bei, sondern stärkte auch die wissenschaftliche Ausbildung der Teilnehmerinnen. Die Schülerinnen entwickelten Kompetenzen in experimenteller Biologie, Programmierung, Dokumentation, Medienproduktion und interdisziplinärer Forschung. Diese Erfahrungen fördern nicht nur das wissenschaftliche Denken, sondern leisten auch einen strategischen Beitrag zur Nachwuchsförderung und Positionierung der Universität Klagenfurt als innovativen Forschungsstandort.

INTRODUCTION

Physarum polycephalum is widely used as a model organism in biological and computational research due to its self-organizing behavior, adaptive network formation, and ability to solve complex optimization problems. Studies have shown that *P. polycephalum* can find efficient paths through mazes [1], develop robust and cost-efficient transport networks [2], and form structures comparable to real-world infrastructure systems such as railway networks [3]. These properties make *P. polycephalum* particularly interesting for research in unconventional computing, optimization, and bio-inspired network design.

These unique properties also make *P. polycephalum* an ideal organism for interdisciplinary educational projects combining biology, mathematics, computer science, and engineering. Based on this research background, the project "Experiments with Slime Molds" was announced as part of the IT internships as follows: "Slime molds are highly interesting creatures. Contrary to what the name suggests, *P. polycephalum* is not a fungus but a plasmodial slime mold that exists as a multinucleated syncytium formed through repeated nuclear divisions without cytokinesis. Slime molds can be used in experiments to solve labyrinths and for network planning. In this practical course, you will work with slime molds in Petri dishes and with a tool that simulates the special behavior of slime molds. Physical obstacles (mountains, lakes) and labyrinths can also be modeled with the help of 3D printing. You should have an interest in biology, mathematics, computer science and scientific experiments”.

In the end, the two interns Viviane Elmenreich and Anastasia Pulvermacher were selected from several applications, both of whom had excellent grades and promising CVs. Both of them attended an academic secondary school (AHS) in Klagenfurt. While their education did not include formal technical training, they exhibited a strong interest in and basic understanding of technological concepts.

Objectives and Learning Outcomes for Interns

The internship offers participants an initial insight into studying and working at an Austrian university. For many, it is also their first experience with academic work and research. Through close interaction with their supervisors, participants gain an authentic impression of everyday university life and research work. In the field of technical sciences in particular, the internship provides an opportunity to experience complex technical issues practically and to become familiar with interdisciplinary approaches. In the current study, working with the biological system *P. polycephalum* and computer-aided simulations of its behavior enabled interns to develop a deeper understanding of scientific and technical issues. Participants were provided opportunities to develop a better understanding of self-organizing processes and acquire basic skills in applying computer-aided methods to analyze complex biological systems.

Research Benefits

An important, research-oriented objective of the internship was to evaluate the existing simulation tool SISMO (Simulation of Slime Molds) [4], [5] in a practical setting. The project involved students with varying levels of prior experience, creating an ideal setting to assess the tool’s usability, clarity, and flexibility. Through hands-on use and feedback from the interns, potential weaknesses in the interface, functionality, and underlying algorithm were identified. These insights were useful for the tool’s future development, contributing to its refinement and applicability in future research and educational contexts. Another aim was to carry out several in vitro experiments whose results could potentially help answer specific research questions. Current investigations, for example, focus on the mechanisms of information dissemination within the slime mold network. Analyzing the uptake and transmission of dyes during dispersal and feeding provided a method to visualize and better understand the processes of information transfer within the network.

Experiment Overview

A series of tasks to be completed during the four-week internship was discussed in advance. These experiments aimed to develop a deeper understanding of slime mold behavior under different conditions and explore slime mold problem-solving abilities. The experiments also demonstrated how slime molds react to various external stimuli and the mechanisms they use to adapt and solve problems. Alongside the in vitro experiments, simulations were carried out with SISMO. The work was documented daily, and progress was presented regularly. A video was made about the internship work. Table 1 provides an overview of the experiments that were planned and prepared before the internship. A detailed description of the tasks carried out can be found in the Methods section.

Tab. 1

Experiments and Tasks
Reproduction of Slime Molds
Influence of Food Colors on Slime Molds
Color Merging within the Slime Mold Network
Slime Molds in Mazes
Regeneration and Healing
Simulations with SISMO
Multimedia Production
Documentation and Reporting
Research and Theoretical Study

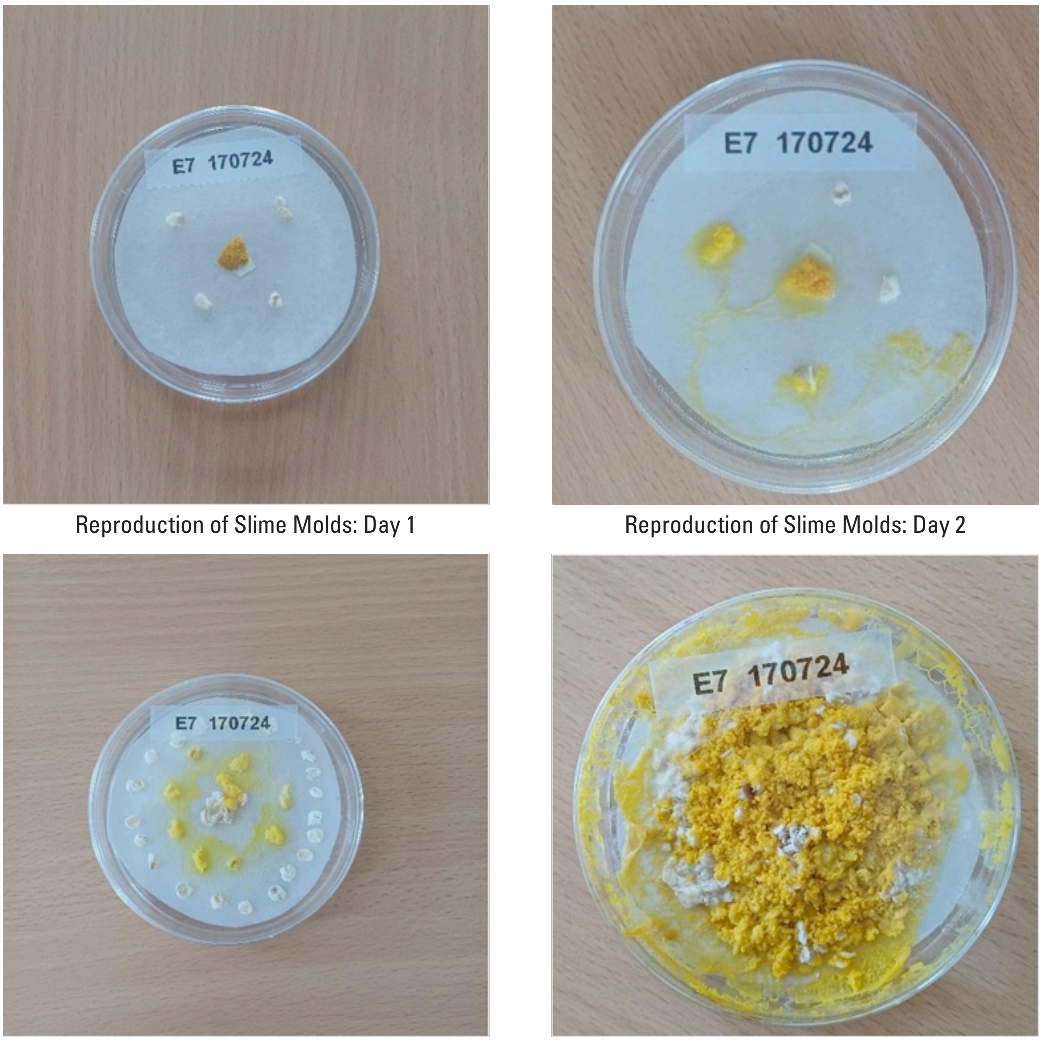
Table 1: Overview of Experiments and Tasks during the Internship

Tabelle 1: *Übersicht über Experimente und Aufgaben während des Praktikums*

EXPERIMENTAL ANALYSIS OF LIVING SLIME MOLDS

Reproduction of Slime Molds

In one of the first experiments, a slime mold sclerotium was placed on moistened filter paper in a Petri dish containing Sabouraud 2% glucose agar as a nutrient medium and oat flakes as nutrient hot spots. Within a few days, active growth toward the placed oat flakes was observed. The slime mold formed a fine network, clearly separated from the original sclerotium. Parts of the grown plasmodium were later cut out and left to dry in order to produce new sclerotia. However, these were not always successfully reactivated. It was assumed that the amount of active slime mold material on the filter paper was insufficient to enable reactivation. A particularly striking example of successful reproduction was seen in another experiment. Here, a sclerotium was again placed on filter paper with nutrient medium and oat flakes. Over several days, the slime mold developed very actively, connecting all the oat flakes in the Petri dish within a dense network, eventually growing over the edge into neighboring dishes and even onto the surface of the storage cabinet. Parts of this plasmodium were removed and specifically dried to produce new sclerotia. Toward the end of the experiment, it was observed that the slime mold might have begun forming fruiting bodies in what could be an indication of another possible reproductive pathway. Targeted experiments for producing new sclerotia were also carried out, in which parts of an active plasmodium were directly dried on filter paper. Some of these sclerotia showed minimal activity even after the drying process had begun, before eventually becoming completely dormant. These experiments demonstrated that slime molds are generally capable of entering a sclerotial state through controlled drying, allowing for its potential long-term preservation. The experiments also showed that the substrate plays a crucial role. While cultivation on filter paper was mostly successful, cultures without filter paper were more prone to mold contamination or showed little to no growth. This suggests that filter paper is beneficial for regulating moisture and maintaining favorable conditions for reproduction. Figure 1 shows one of the experiments carried out to reproduce slime molds. In summary, reproduction of slime molds through sclerotia is a robust and effective mechanism for ensuring the long-term survival of these organisms. Through targeted cultivation, drying, and rehydration, slime molds can be reused and reactivated multiple times, provided there is enough active material and suitable environmental conditions.



Reproduction of Slime Molds: Day 1

Reproduction of Slime Molds: Day 2

Reproduction of Slime Molds: Day 3

Reproduction of Slime Molds: Day 6

Fig. 1

Figure 1: Experiment: Reproduction of Slime Molds

Abbildung 1: *Experiment: Vermehrung von Schleimpilzen*

Influence of Food Colors on Slime Molds

A suite of experiments investigated whether the slime mold *P. polycephalum* absorbs food dyes and how these dyes influence its growth behavior. The dyes are also used to visualize the growth pathways. Petri dishes with a layer of solidified agar-agar served as the experimental setup. Circular filter paper was placed on the agar to improve moisture distribution. The slime mold sclerotia were placed in the center of the dish on the moist filter paper and lightly moistened with sterile water to reactivate them. To prepare food sources, oat flakes were treated with various food dyes that were applied with a pipette. The oat flakes were dried to prevent the color from spreading uncontrollably on the agar. The colored oat flakes were then arranged evenly, two to three centimeters apart, around the slime mold.

The spread of the slime mold was observed and documented over the course of several days. Daily camera recordings and microscopic images were used for analysis. Specifically, we recorded which colored food sources were reached, whether there was a preference or avoidance of certain colors, and if the organism took up color. A microscope was used to check for structural or color changes in the slime mold resulting from dye uptake. Additionally, the growth structures revealed by dyes (e.g., pseudopodia and tube networks) were examined for their shape, branching, and orientation. It was hypothesized that the slime mold would actively move toward the dyed oat flakes. Partial dye uptake by the organism appeared possible and manifested as slight color changes. Further studies would supplement this setup with other environmental factors, such as light, temperature, or humidity, to analyze interactions between chemical and physical stimuli. Additionally, using several dyes simultaneously would open up the possibility of recording the behavior of *P. polycephalum* in more complex decision-making situations.

The aim of the two experiments, *Colored Oat Flakes 1* (blue and red) and *Colored Oat Flakes 2* (black and pink), was to investigate whether and how slime molds absorb dyes from colored food sources and whether this affects the color of the plasmodium. In the first experiment, the slime mold clearly responded to the red oat flakes. By the second day, it had started to grow toward it and had eventually consumed it. Over the following days, the plasmodium took on an orange-reddish hue, indicating that the dye had been absorbed and distributed throughout the organism. Although there were no further changes after that point and the slime mold eventually dried out due to low humidity, a noticeable color change was observed. In the second experiment, the slime mold initially spread in two directions, toward a black oat flake and a non-dyed one. Over time, it showed a preference for the colorless oat flake, consuming them and continuing to be fed non-dyed food. No clear and consistent color change was observed. However, later in the experiment, it was noted that the section of the plasmodium near the pink oat flake had taken on some of its color, while the rest of the organism remained yellow. Overall, the experiments showed that *P. polycephalum* is capable of absorbing dyes from colored food, though the extent and uniformity of the color change depend on the specific dye and the feeding behavior of the slime mold. A uniform color shift across the entire plasmodium was only clearly observed in the experiment involving the red oat flake. In both cases, it was also observed that overly moist conditions increased the risk of mold contamination, influencing the outcome of the experiments.

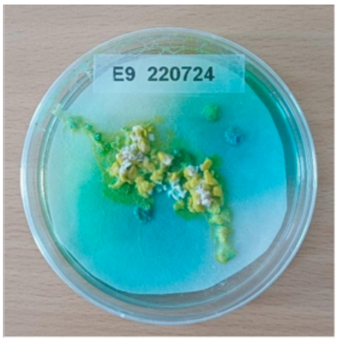
Color Merging within the Slime Mold Network

This experiment investigated how the slime mold *P. polycephalum* takes up and merges food dyes when exposed to differently colored nutrient sources. Unlike animals, slime molds lack specialized transport systems, such as blood vessels. Instead, nutrients and potential dyes are absorbed across their entire body and distributed via cytoplasmic streaming. Consequently, when exposed to two distinct dyes, color merging may occur, particularly in regions where slime mold networks merge. The experimental setup consisted of Petri dishes containing solidified agar with cut filter paper on top to enhance moisture retention. Reactivated *Physarum* sclerotia are placed in the center of the moistened filter paper. Blue and yellow food colorings were used to dye oat flakes, which were then allowed to dry to prevent dye diffusion on the agar. The flakes were arranged on opposite sides of the Petri dish, approximately 2–3 cm from the slime mold. The slime mold's growth and expansion were monitored daily with photographic and video documentation focusing on dye uptake and the formation of colored pathways. Intersections of differently colored slime mold networks were examined microscopically to detect potential color changes indicative of dye merging (e.g., green resulting from blue and yellow). The null hypothesis was a lack of dye merging, which is manifested as distinct color regions due to limited internal transport, and the alternate hypothesis was partial dye merging, which would be observable as new colors at network intersections reflecting intracellular transport and fusion of dyes. The analysis involved a detailed assessment of color distribution and merging patterns to elucidate the mechanisms by which dyes are transported within the slime mold.

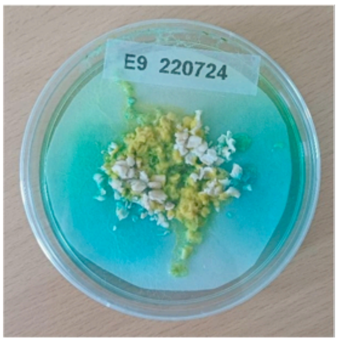
The experiment focused on how the slime mold responds to the simultaneous intake of two differently colored oat flakes, specifically, one blue and one yellow. The aim was to establish whether the colors would blend within the plasmodium or remain confined to the points of contact. On the first day, the slime mold exhibited initial activity and started to grow toward the colored oat flakes. By the second day, it had consumed both the blue and yellow flakes. Consequently, the entire slime mold network turned green, indicating that it had absorbed and merged the dyes, distributing the combined color throughout its body. Over the following days, the slime mold was fed uncolored oat flakes. It was observed that the previously green branches began to retract and that newly formed areas of the plasmodium returned to their original yellow color. This suggests that the dye was either broken down or diluted over time through the growth of new, undyed tissue. Overall, the experiment demonstrated that *P. polycephalum* was capable of absorbing and merging food dyes within its network, and that this coloration was reversible when uncolored food was introduced. Additionally, time lapse imaging offers dynamic insights into the progression of dye transport and merging over time. Figure 2 shows the progress of the experiment.

Color Merging within the Slime Molds Network: Day 1

Color Merging within the Slime Molds Network: Day 2



Color Merging within the Slime Molds Network: Day 3



Color Merging within the Slime Molds Network: Day 4

Color Merging within the Slime Molds Network: Day 5

Color Merging within the Slime Molds Network: Day 8

Fig. 2

Figure 2: Experiment: Color Merging within the Slime Molds Network

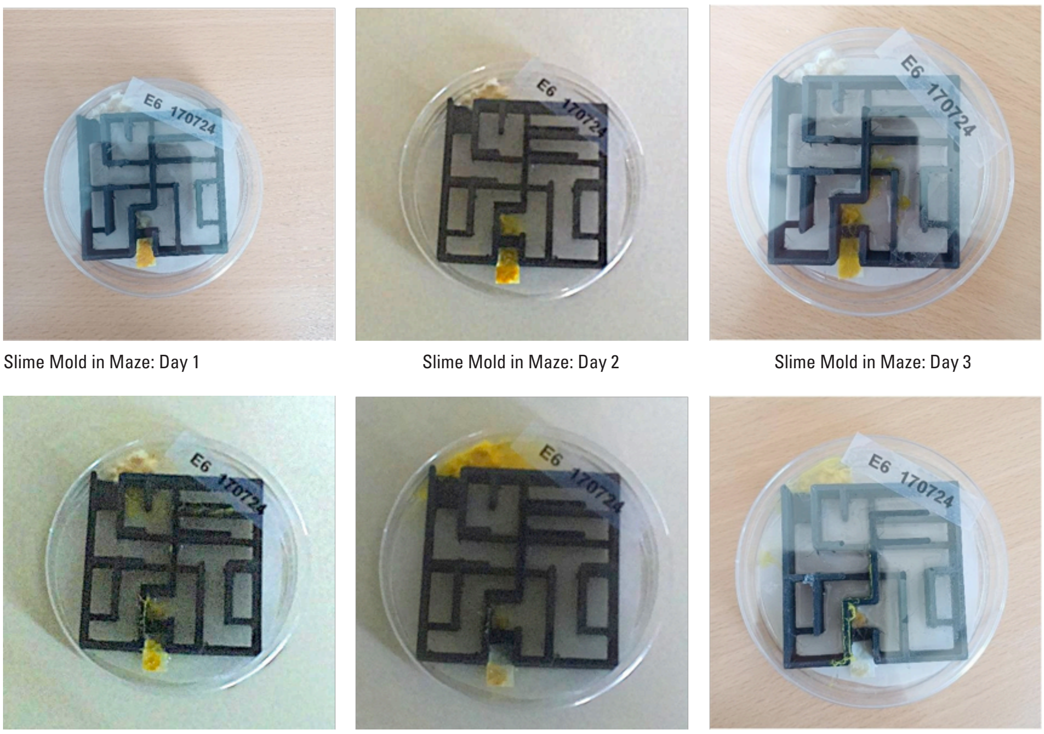
Abbildung 1: *Experiment: Farbvermischung im Schleimpilznetzwerk*

Future work will explore additional dye combinations, such as red and blue or red and yellow, to evaluate the generalizability of color merging behavior. Since different food colorings contain distinct chemical compounds and pigments, future studies should also investigate whether the observed responses of *P. polycephalum* depend on the chemical composition of the dyes rather than color alone.

Slime Molds in Mazes

This experiment combined in vitro experiments with 3D design and 3D printing. The task was to design a maze whose entrances and exits are clearly defined and to create it using a 3D printer. It was possible to delegate this task to a student who performed an internship on the subject of 3D printing. The experiment used slime mold cultures, a 3D-printed maze, Petri dishes with agar-agar, oatmeal as a food source, filter paper, a microscope with a camera, sterile water, a timing device (e.g., stopwatch) and documentation tools such as a notebook and a camera. The printed maze was positioned on a Petri dish prepared with agar-agar and filter paper, and a slime mold was applied at the maze entrance. A small quantity of moist oat flakes was placed at the end of the maze. The growth of the slime mold through the maze was observed and the time taken by the organism from the entrance to the exit measured.

The hypothesis that slime molds are able to demonstrate their ability to solve problems is justified by the expectation that they will find the shortest or most efficient path to the food source. Slime trails were expected to be achieved, representing pathway marking. The recorded times and paths should provide valuable information about the subjects' navigation and decision-making behavior. Daily monitoring was used to document progress, whereby the filter paper was constantly supplied with moisture to ensure optimum growth conditions. The measurements of time and path allowed conclusions to be drawn about the navigation strategies of the slime mold. Optionally, the oat flakes could be dyed with food coloring at the exit to make the path of the slime mold more visible. Figure 3 shows the results of the experiment.



Slime Mold in Maze: Day 1 | Slime Mold in Maze: Day 2 | Slime Mold in Maze: Day 3

Slime Mold in Maze: Day 4 | Slime Mold in Maze: Day 5 | Slime Mold in Maze: Day 6

Fig. 3

Figure 3: Experiment: Slime Molds in Mazes

Abbildung 3: *Experiment: Schleimpilze in Labyrinthen*

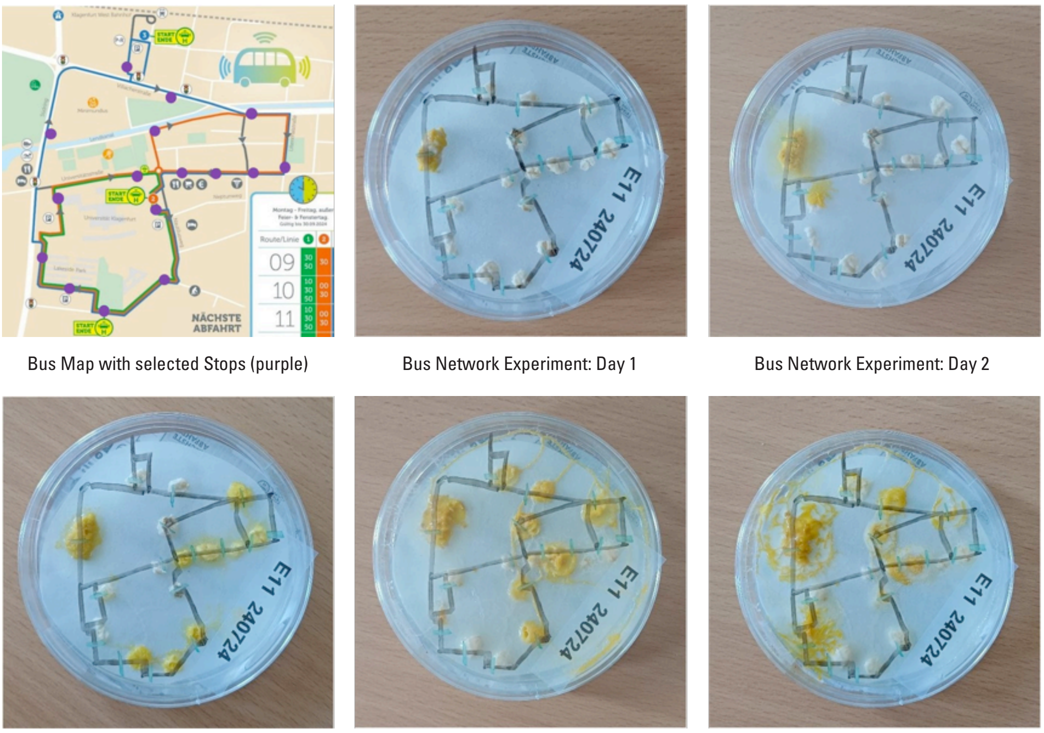
The extension of the object of investigation includes the use of more complex maze designs to further evaluate problem-solving skills. In addition, the influence of different environmental conditions, such as light, humidity, and temperature on maze traversal was investigated. Several food sources were placed in the maze in order to observe the navigation behavior with competing targets.

Regeneration and Healing

This experiment investigated the ability of slime molds to regenerate damaged or divided structures. It was hypothesized that slime molds demonstrate a remarkable ability to regenerate by rapidly reconnecting damaged or divided parts into a complete organism. The duration of regeneration would vary depending on factors such as the size of the divided pieces and environmental conditions. A Petri dish with solidified agar-agar was prepared, and a healthy slime mold culture was carefully cut into several pieces using a scalpel or sharp knife. The divided slime mold pieces were then placed close together on the agar surface in the Petri dish, allowing them to come into contact with each other. Throughout the experiment, the regeneration process was observed daily, and the time required for the divided pieces to grow back into a complete slime mold was recorded. Photos or videos were regularly taken to document the development. The Petri dish was kept moist at all times to ensure optimal growth conditions. The regeneration time was measured for each divided piece, and microscopic examination of the regenerated areas was conducted to assess precisely how regeneration occurs and whether there are any structural differences compared to the original state.

Bus Network

The two interns independently designed and carried out another experiment based on their own idea. This experiment aimed to investigate whether *P. polycephalum* would form a network between selected locations resembling the route map of the autonomous shuttle system operating in Klagenfurt. Out of the 18 total stops, 16 shuttle stops were selected and represented as nodes on an experimental substrate; each node was marked with a food source to attract the slime mold. The hypothesis was that the resulting network structure would differ significantly from the actual shuttle route, since the slime mold is not constrained by infrastructure such as roads or traffic regulations. This exploratory experiment provided insight into the differences between human-engineered transportation networks and those emerging from self-organizing biological systems and offered a new approach to analyzing biologically inspired optimization strategies. In her internship report, Viviane Elmenreich summarized the procedure and observations of the experiment as follows: On the first day of the experiment, a Petri dish was prepared



Bus Map with selected Stops (purple) | Bus Network Experiment: Day 1 | Bus Network Experiment: Day 2

Bus Network Experiment: Day 3 | Bus Network Experiment: Day 6 | Bus Network Experiment: Day 10

Fig. 4

Figure 4: Bus Network Experiment

Abbildung 4: *Experiment: Busnetzwerk* with agar-agar and filter paper. A printed image of the bus network was attached to the underside of the dish and a diagram was drawn on the lid. The selected 16 stations were marked on the filter paper and oat flakes were placed on them. Part of a slime mold from a previous experiment was added to the dish. The dish was then stored in the dark. The very next day, the slime mold began to spread and reach the oat flakes. Over the following days, it continued to grow, connecting several stations. The experiment was completed on day seven. By this time, the slime mold had formed its own network, which did not correspond exactly to the original bus network. Notably, many connections ran along the edge of the Petri dish instead of taking the shortest route. Figure 4 shows photographic documentation of the experiment.

SIMULATIONS WITH SISMO

In this task, the interns worked with the simulation tool SISMO, which is used to model the behavior of slime molds. They compared the resulting simulations with experimental data to evaluate the accuracy and reliability of the model. They also familiarized themselves with the NetLogo programming language in order to subsequently expand SISMO. The goal was to adapt the tool to specific experiments in order to achieve the most accurate possible representation of the actual behavior of slime molds.

The simulation tool SISMO was used to model the specific behavior of slime molds during foraging and network planning. The simulation results were subsequently compared with experimental data. Initially, it was ensured that the SISMO software was installed on the computer and that the basic functions and user interface of the tool were understood. Data from the conducted experiments, such as growth times, paths, and color mixtures, were collected and documented. A new simulation project was then created in SISMO, and the parameters from the experiments, including the positions of food sources, environmental conditions, and maze designs, were defined. The simulations replicate the behavior of slime molds during foraging and network formation. The resulting simulation data were observed and recorded. These results were compared with actual experimental findings to identify similarities and differences in behavioral patterns, paths, and durations.

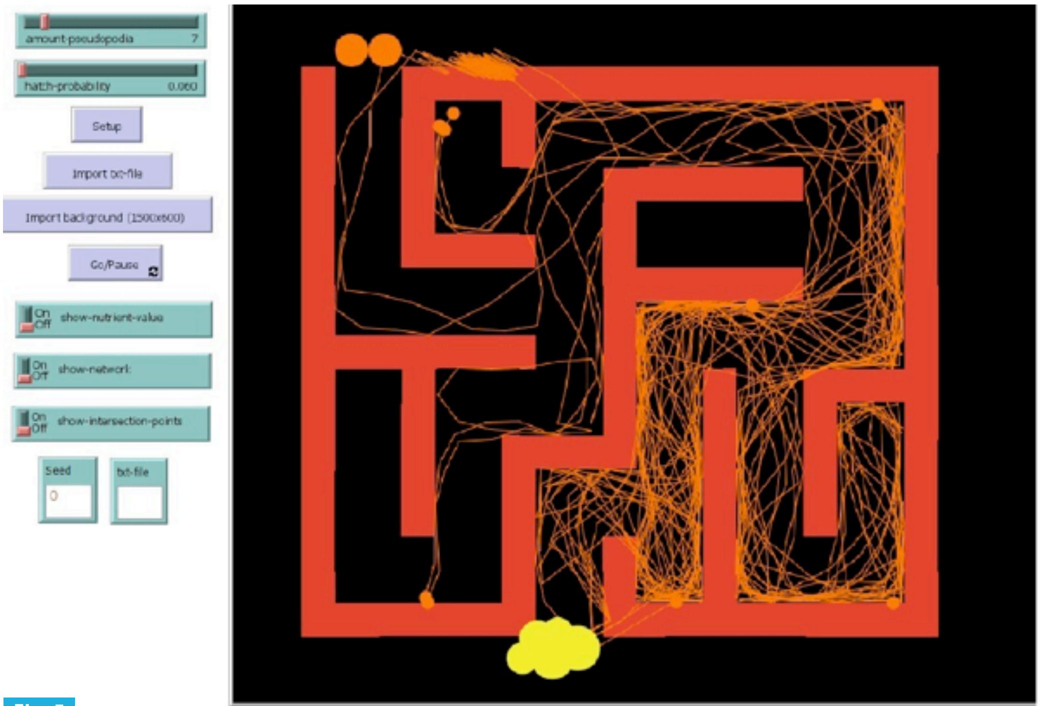


Fig. 5

Figure 5:
SISMO Simulation of the Slime Molds in Mazes Experiment

Abbildung 5:
SISMO-Simulation des Schleimpilz-Labyrinth-Experiments

Furthermore, the ability of the simulation to accurately reproduce observed color mixtures and regeneration processes was analyzed. All performed simulations and their outcomes were thoroughly documented, including screenshots and detailed notes on significant observations. For example, Figure 5 illustrates the maze experiment performed in silico as a SISMO simulation.

DOCUMENTATION

Multimedia Production

The tasks of multimedia production included the development of a concept for an informational video about slime molds, including the creation of a storyboard and a shooting schedule. Footage was then taken of slime molds as they grew and during various experiments. The collected material was then edited and supplemented with a suitable narrative. The aim of this task was to create a clear and informative video that conveys the characteristics and behavior of slime molds as well as the experiences gained during the internship. In addition, the interns learned how to use video editing software and thus expanded their technical skills in the field of media production.

Reporting

As part of the internship, participants kept a daily journal in which they recorded all activities and observations. In addition, they wrote weekly reports summarizing their progress and interim results. At the end of the internship, they prepared a comprehensive final report that documented all experiments conducted, their results, and key insights. The goal of this task was to develop skills in scientific documentation and structured reporting.

Research and Theoretical Study

Participants were tasked with conducting literature research on slime molds and their properties, summarizing recent scientific studies. They also focused on specific topics, such as the application of slime molds in energy technology, and prepared a presentation to share their findings. The goals of this task were to deepen theoretical knowledge and to enhance research and presentation skills.

RESULTS

The results are presented through three complementary perspectives: the learning outcomes achieved by the interns, the benefits generated for ongoing research, and the program's strategic relevance to the University of Klagenfurt. This differentiation enables a more nuanced analysis of the program's overall impact, highlighting its multifaceted value in educational, scientific and institutional terms.

Learning Outcomes for Interns

The internship program gave participating students the opportunity to develop a wide range of skills and gain experience in various fields. A key learning outcome was the practical execution of biological experiments, through which interns gained foundational knowledge of biology and experimental methodology. Using the SISMO simulation framework further provided hands-on training in information technology and computational modelling, encouraging interdisciplinary thinking at the intersection of biology and technology. Additionally, interns were actively involved in multimedia production, scientific documentation and structured research process reporting. These activities strengthened their communication skills and deepened their understanding of how to present complex information in an accessible way. Finally, independent study of the literature and theoretical engagement with the research topics fostered critical thinking and a reflective approach to scientific enquiry.

In the following report, Viviane Elmenreich, an intern, describes their personal impressions and the professional and practical experience they gained during her internship:

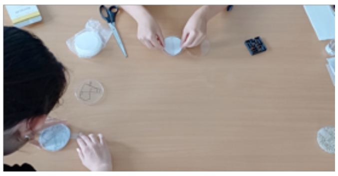
EXPERIMENTS ON PHYSARUM POLYCEPHALUM AT THE UNIVERSITY OF KLAGENFURT

> The experiments were conducted in July 2024 and focused on experimental work with *Physarum polycephalum*. The primary objective was to evaluate the organism's problem-solving capabilities by conducting independent experiments and establishing new sclerotia cultures for future use.
>
> Daily activities included the systematic observation of slime mold growth across all active Petri dishes, photographic documentation, and nutrient replenishment. Fungal contamination was recorded where present, and hypotheses were formulated to explain its occurrence. All observations and photographic evidence were incorporated into the project documentation on a daily basis.
>
> The first week was dedicated to an intensive literature review encompassing scientific papers, online resources, and video material on *P. polycephalum*, alongside experimental preparation. Media preparation involved cooking agar-agar, casting it into Petri dishes, and placing pre-cut filter paper on top. Sclerotium reactivation required ensuring adequate moisture and proximity to a food source. For more complex experiments, oat flakes were dyed with food coloring and a 3D-printed labyrinth was used as an experimental substrate, with the 3D printing carried out by a fellow intern.
>
> A Raspberry Pi was configured and programmed to photograph the slime mold in the maze at 30-minute intervals, with two LED lamps triggered at each capture. Due to insufficient illumination, the overnight photographs could not be utilized. The labyrinth experiment was additionally modelled in SISMO; the in vitro result — in which the slime mold grew along the walls to reach the food source — was not reproduced by the simulation, an observation with direct relevance to model refinement.
>
> Progress meetings were held at two-week intervals to review results and plan subsequent experiments. The internship concluded with the production of a short documentary film on the project. The practical work provided a foundation for scientific thinking and independent experimental methodology.

During their four-week internship at the University of Klagenfurt, the interns developed a wide range of skills in experimental biology, information technology and scientific communication. Working independently, they designed and conducted a series of experiments on *P. polycephalum*, focusing on the reactivation of sclerotia, behavioral observation and nutrient response. They gained practical experience in preparing media (agar-agar), maintaining cultures and documenting developmental stages through systematic photography. The internship also involved integrating a Raspberry Pi system to automate time-lapse photography and using SISMO, a simulation tool for modelling slime mold behavior. By comparing in vitro and in silico results, the interns developed a deeper understanding of the differences between experimental and simulated environments. Furthermore, the interns demonstrated their ability to work independently, formulate hypotheses and critically reflect on experimental outcomes. These activities strengthened their scientific reasoning and provided a foundational experience in

Setup of the Maze Experiment

Setup of the Color Merging Experiment



Setup of the Bus Experiment

Fig. 6

Figure 6: Interns performing various Experiments

Abbildung 6: *Praktikantinnen bei verschiedenen Experimenten*

interdisciplinary research, bridging biology and computer science. In addition, a video documenting the experimental process was produced as part of the internship. Not only were the experiments filmed, but the interns also wrote their own script to present the content in a structured way. The filming, some of which took place in a professional video studio, was planned and carried out independently. Through these tasks, the students acquired and deepened essential skills in media production, project organization, and professional presentation. In particular, creating the script independently and practically implementing the filming promoted an understanding of how to convey scientific content clearly and appealingly. Various studies, such as the study by Yael Wolinsky-Nahmias and Arthur H. Auerbach [6], show that internship programs of various designs can achieve a high level of impact and satisfaction if central elements are integrated accordingly. This is particularly true if they promote initiative, impart skills, and are experienced as meaningful. Figure 6 shows the interns performing various experiments.

Research Benefits

During the internship, the SISMO tool was systematically tested in a practical environment. The aim was to evaluate its user-friendliness, functionality, and scalability in real-world scenarios. Having students with different levels of technical knowledge use the application enabled a more detailed analysis of its usability. It was found that, in its previous form, SISMO could only be used intuitively to a limited extent by inexperienced users. The weaknesses identified related particularly to the user interface and initial control of simulation elements, such as placing food sources or starting points for slime mold networks. Subsequently, targeted improvements were made to increase accessibility and optimize the system for educational and teaching contexts in particular.

Additionally, the interns adapted and expanded the underlying code base to align it with specific experimental requirements. For instance, new dye models were integrated to simulate information transfer in the network, and the simulation system's existing behavioral rules were modified accordingly. These modifications were successfully implemented and tested, demonstrating their seamless integration with the existing system components.

Several in vitro experiments with *P. polycephalum* were conducted in parallel with the software development. These experiments aimed to observe the real-world behavioral patterns of the slime mold with regard to resource utilization, network expansion and transport processes, and to compare these with simulation results. One notable experimental setup involved selectively colorizing food sources to investigate how information is transmitted or replaced within the biological network. These data will serve as a foundation for the ongoing development of SISMO and are currently being used to simulate information propagation within the model.

Overall, the close interplay between experimental work and digital modelling has contributed to the further development of the simulation tool and deepened our understanding of self-organizing biological networks. The insights gained during the internship are currently informing ongoing research efforts and demonstrating the potential of SISMO as a tool for supporting data-driven modelling of bio-inspired systems.

Strategic Importance for the University of Klagenfurt

Zenobia Ismail's work [7] examines the advantages of internship programs, focusing on perceived improvements in skills and employment outcomes, particularly within the fields of information technology and business. It is shown that companies see interns as low-cost workers who can support them, especially during labor-intensive periods [8], and take on projects that would otherwise not be implemented [9]. Furthermore, internships can reduce long-term recruitment and training costs, as they act as a trial period that can lead to permanent employment [10], [11], [12]. The practical experience gained during an internship shortens the onboarding period for interns compared to that for new employees [12]. A student internship at a university, particularly in a technical or research-related field, offers the opportunity to recruit potential students at an early stage, rather than being focused on the immediate workload. Such internships give institutes the chance to get to know talented and interested young people, inspire them to study at their university, and introduce them to scientific work early on. If the interns later return as students, both parties benefit: the university gains committed young talent, and the students are already familiar with the processes and key contacts, making it easier for them to start working as a study assistant or tutor. In the long term, the mentoring effort pays off through the targeted promotion of young talent and stronger ties to the university.

A qualitative study by Saraiva et al. [13] further found that participants in research internships showed a strong subsequent willingness to pursue careers in STEM fields. Beyond recruitment, the internship also fosters sustainable networking between the university and the regional education sector, creating opportunities for future collaborations and strengthening the university's visibility as an innovative, socially responsible research institution.

Although no studies or concrete figures are yet available on how many former participants in the IT internship have subsequently decided to study at the Institute of Technical Sciences (TEWI) or at the University of Klagenfurt in general, there is nevertheless clear potential for an internship to arouse interest in technical fields of study at an early stage and thus contribute to the targeted recruitment of qualified young students.

DISCUSSION

The project *Experiments with Slime Molds*, supported within the 2024 IT Internship Programme at the University of Klagenfurt, which focused on experimental work with *P. polycephalum*, is a compelling example of how interdisciplinary research environments can promote pedagogical development, facilitate ongoing scientific research and contribute strategically to institutional objectives.

Case studies of comparable interdisciplinary research internships have shown that the combination of hands-on experimentation, guided reflection, and independent project work is particularly effective in developing scientific self-efficacy among secondary school participants [13]. The present case is consistent with these findings, illustrating how a structured four-week program can simultaneously serve educational, research-oriented, and institutional objectives.

One of the program's most important outcomes was the comprehensive learning experience it offered the interns. They participated in a variety of activities, ranging from hands-on biological experiments to computer modelling and media production. This allowed them to develop both hard and soft skills. Notably, they learned to independently plan, conduct and document experiments, work with living organisms, and handle scientific tools such as the SISMO framework and Raspberry Pi-based data acquisition systems. Throughout the internship, the participants deepened their understanding of biological systems and information transmission in slime molds, while also strengthening their critical and reflective thinking skills. Integrating theoretical knowledge, literature research and practical application fostered a well-rounded scientific mindset. Including multimedia elements, such as writing and producing a short film, added an important communicative dimension to the interns' experience, teaching them to convey complex scientific ideas clearly and creatively.

The internship also generated valuable insights for ongoing research projects. By systematically testing the SISMO tool, the interns helped to identify issues with the software's usability and limitations, particularly with regard to accessibility for inexperienced users. These findings informed targeted improvements to the tool's interface and functionality, particularly with regard to educational applications. The interns also contributed to the system's development by adapting code and incorporating new features, such as color-based data models that simulate information propagation in biological networks. The effectiveness of these enhancements was validated through parallel in vitro experiments, which offered direct comparisons between simulated and real-world slime mold behavior. This approach helped refine SISMO and generated new data for future bio-inspired modelling. For instance, the strategic use of experiments involving dyed oat flakes offered insights into how slime molds integrate and distribute information within their networks. This concept has broader implications for understanding self-organizing systems in both natural and artificial contexts.

Beyond its scientific and educational dimensions, the internship program supports the University of Klagenfurt's broader strategic objectives. As different studies have highlighted, internships serve as a valuable recruitment tool, offering universities the opportunity to attract motivated students at an early stage. By working on engaging, meaningful projects, young participants develop a connection with the institution that can lead to future enrollment, employment or long-term collaboration. In technical and research-focused fields in particular, internships act as trial periods, enabling both the institution and the intern to evaluate their long-term compatibility. Although concrete data on retention and enrollment outcomes is not yet available, the potential impact of these programs on university-community engagement and talent development is evident. By investing in structured, interdisciplinary internships like this one, the University of Klagenfurt strengthens its scientific output and reputation, actively contributing to the development of future researchers and innovators.

REFERENCES

[1] T. Nakagaki, H. Yamada, and A. Tóth, "Maze-solving by an amoeboid organism," *Nature*, vol. 407, no. 6803, p. 470, 2000, doi: 10.1038/35035159

[2] T. Nakagaki, R. Kobayashi, Y. Nishiura, and T. Ueda, "Obtaining multiple separate food sources: behavioural intelligence in the *Physarum* plasmodium," *Proceedings of the Royal Society B: Biological Sciences*, vol. 271, no. 1554, pp. 2305–2310, 2004, doi: 10.1098/rspb.2004.2856

[3] A. Tero, S. Takagi, T. Saigusa, K. Ito, D. P. Bebber, M. D. Fricker, K. Yumiki, R. Kobayashi, and T. Nakagaki, "Rules for biologically inspired adaptive network design," *Science*, vol. 327, no. 5964, pp. 439–442, 2010, doi: 10.1126/science.1177894

[4] K. Wogatai, "SISMO (SImulation of Slime MOlds): a slime mold based algorithm and its application in traffic management," Master Thesis. Alpen Adria University of Klagenfurt, Klagenfurt am Wörthersee, 2022. [Online]. Available: https://netlibrary.aau.at/obvuklhs/download/pdf/8440422, checked on 6/11/2026.

[5] E. Sinanović, "Simulation and mobility planning with a slime mold based algorithm," Master Thesis. Alpen Adria University of Klagenfurt, Klagenfurt am Wörthersee, 2022. [Online]. Available: https://netlibrary.aau.at/obvuklhs/download/pdf/8504854, checked on 6/11/2026..

[6] Y. Wolinsky-Nahmias and A. H. Auerbach, "Evaluating the design and benefits of internship programs," *Journal of Political Science Education*, vol. 18, no. 4, pp. 584–604, 2022, doi: 10.1080/15512169.2022.2109481

[7] Z. Ismail, "Benefits of internships for interns and host organisations," K4D Helpdesk Report. University of Birmingham, Birmingham, UK, 2018. [Online]. Available: https://gsdrc.org/wp-content/uploads/2018/07/Internships.pdf, checked 6/11/2026..

[8] J. V. Elarde and F.-F. Chong, "The pedagogical value of 'eduployment,'" in *Proceedings of the 13th Annual Conference on Information Technology Education (SIGITE '12)*, Calgary, Canada, Oct. 11–13, 2012. New York, NY: ACM, 2012, pp. 189–194, doi: 10.1145/2380552.2380607

[9] L. Galloway, A. Marks, and S. Chillas, "The use of internships to foster employability, enterprise and entrepreneurship in the IT sector," *Journal of Small Business and Enterprise Development*, vol. 21, no. 4, pp. 653–667, 2014, doi: 10.1108/JSBED-09-2014-0150

[10] L. Holyoak, "Are all internships beneficial learning experiences? An exploratory study," *Education + Training*, vol. 55, no. 6, pp. 573–583, 2013, doi: 10.1108/ET-02-2012-0024

[11] C. Dobratz, R. Singh, and A. Abbey, "Using formal internships to improve entrepreneurship education programs," *Journal of Entrepreneurship Education*, vol. 18, pp. 96-110, 2014.

[12] C. P. Maertz Jr., P. A. Stoeberl, and J. Marks, "Building successful internships: lessons from the research for interns, schools, and employers," *Career Development International*, vol. 19, no. 1, pp. 123–142, 2014, doi: 10.1108/CDI-03-2013-0025

[13] E. Saraiva, S. Silva, J. Castro, D. Araújo, C. Almeida, and M. M. Azevedo, "Students' summer internships in a research centre: The impact on scientific literacy and the choice of a career in the STEM fields," *Heliyon*, vol. 11, no. 4, e42472, 2025, doi: 10.1016/j.heliyon.2025.e42472

ABOUT THE AUTHORS

Kristina Wogatai
Networked and Embedded Systems
University of Klagenfurt
Austria
kristina.wogatai@aau.at

Viviane Elmenreich
Klagenfurt, Austria

Anastasia Pulvermacher
Klagenfurt, Austria

Wilfried Elmenreich
Networked and Embedded Systems
University of Klagenfurt, Austria
wilfried.elmenreich@aau.at

BACK TO CONTENT