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Two-Year Progress of Pilot Research Activities in Teaching Digital Thinking Project (TDT)

Abstract

This article presents a progress report from the last two years of the Teaching Digital Thinking (TDT) project. This project aims to implement new concepts, didactic methods, and teaching formats for sustainable digital transformation in Austrian Universities' curricula by introducing new digital competencies. By equipping students and teachers with 21st-century digital competencies, partner universities can contribute to solving global challenges and organizing pilot projects. In line with the overall project aims, this article presents the ongoing digital transformation activities, courses, and research in the project, which have been carried out by the five partner universities since 2020, and briefly discusses the results. This article presents a summary of the research and educational activities carried out within two parts: complementary research and pilot projects.

Keywords

digital transformation, digital competencies, non-computer/computer scientists, computational thinking

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Zwei Jahre Fortschritt der Pilotforschungsaktivitäten im Projekt „Teaching Digital Thinking“ (TDT)

Zusammenfassung

Dieser Beitrag präsentiert die Fortschritte des Projekts Teaching Digital Thinking (TDT) der letzten zwei Jahre. Das Projekt zielt darauf ab, neue Konzepte, didaktische Methoden und Lehrformate für eine nachhaltige digitale Transformation in die Curricula der österreichischen Universitäten zu implementieren, indem neue digitale Kompetenzen verankert werden. Durch die Vermittlung von digitalen Kompetenzen für das 21. Jahrhundert an Studierende und Lehrende können die Partneruniversitäten einen Beitrag zur Lösung globaler Herausforderungen leisten. In Übereinstimmung mit den übergeordneten Projektzielen werden in diesem Beitrag die laufenden Aktivitäten, Lehrveranstaltungen und Forschungsarbeiten zur digitalen Transformation, die von den fünf Partneruniversitäten seit 2020 durchgeführt werden, vorgestellt und die Ergebnisse kurz diskutiert.

Schlüsselwörter

digitale Transformation, digitale Kompetenzen, Nicht-Informatiker:innen/Informatiker:innen, computational thinking

1 Teaching Digital Thinking (TDT)

Digital aspects are becoming increasingly important, and society is changing through digital transformation. Demand for far-reaching digital competences and the ability to solve problems creatively using digital media and data is increasing. In addition to the digital transformation, students today need extensive digital competencies in the areas of learning with digital media, learning about digital media, and learning in the age of digitality (MUUß-MERHOLZ, 2022; BRINDA et al., 2019). Promotion of such digital competencies requires appropriate professional teachers (PETKO, DÖBELI HONEGGER & PRASSE, 2018).

In the evolving information age, every university student needs basic digital competencies. The need for non-computer scientists to be digitally literate in their fields and to work in collaboration with computer scientists emerges as an essential requirement of the new century. Therefore, there is a need to discuss the essential digital competencies that shape the effects of digital transformation on society with computer scientists and non-computer scientists, and the definition of these competencies. While the TDT project developed to respond to this need has completed its second year, the study presents the progress achieved thus far and summarizes the TDT project's outcomes and the ongoing and completed research carried out across Austria in line with the common aims of the TDT project and its results (see Figure 1).

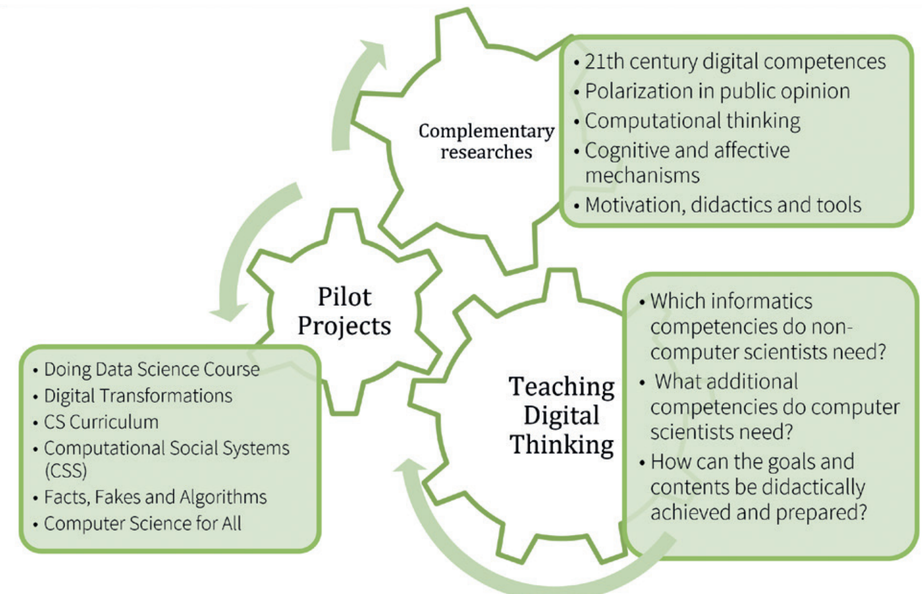

Fig. 1: The structure of TDT

Basic digital competence emerges as one of the essential requirements for every university student in the 21st century. The TDT project aims to identify the primary digital skills and challenges of teaching non-computer scientists to be digitally literate in their fields and collaborate with computer scientists. The existing models of digital competences were examined in detail, and it is concluded that the European competence model, DigComp, is best suited as a common basis. Developing new content based on the identified digital skills aims to describe the new didactic methods and concepts for teaching the skills required for understanding, shaping, and critically reflecting on digitalization. First, the paper summarizes the surveys conducted by research partners and complementary studies conducted toward this aim. Another primary goal of the TDT project is the development of new teaching and learning opportunities, such as learning sequences, modules, extension studies, and bachelor's and master's studies. Several courses and Massive Open Online Courses (MOOC) are presented, followed by summaries of the conducted research. Didactic concepts in teacher education consider the target group of disseminated knowledge: teachers and students in teacher education. The core tasks to develop the didactic concepts include learning about digital transformation, learning with digital technologies, and learning for digital transformation. Developing and implementing teaching and learning activities offers different granularity levels, from teaching and learning sequences over courses to the level of curricula. Many pilot projects are performed on an interdisciplinary basis in humanities and social sciences, natural and engineering sciences, computer science, and teacher education at the partner universities in Austria. In the next section, the pilot projects and accompanying research are presented.

2 Complementary research

2.1 Pre-service teachers' views on Teaching Digital Skills in secondary education

The research described in this part was conducted by the research group CSLEARN at the Faculty of Computer Science at University of Vienna (UniVie). The main aim is to examine how pre-service teachers perceive the role of the teacher training program at UniVie in cooperation with Austria's North-Eastern University Colleges of Teacher Education to prepare them to impart digital competencies.

The research method (AMBROS et al., 2022) was an online survey consisting of 21 open- and closed-format questions. The survey gathered the students' opinions of and experiences with the mediation of digital competencies in their studies.

An essential result from the analyses was high divergence among the students about how prepared they felt to impart digital skills. The reasons provided are manifold, including differences in the course offerings and didactics and variations in the perceived need and intensity of imparting digital skills to secondary-level students. Interestingly, most students shared that they acquired most of their digital competencies in a self-organized way. In connection with the previously mentioned findings, this implies that self-acquisition, while still a viable option, is insufficient for mastering digital competencies in the professionality and depth needed. In addition, students stated that digital competencies should be included in the general basics of educational sciences, which is the teacher education portion thousands of students attended. This calls for developing suitable, innovative approaches to accommodating students' needs.

In short, this study revealed that, while pre-service teachers acquire a significant range of digital skills, many of them feel insufficiently prepared by their teachers' training programs to impart digital skills in their future profession. Thus, self-acquisition, which many students had to perform, is an insufficient form of knowledge acquisition and must be complemented by appropriate instruction and/or guidance. This implies the need to design strategies and develop concrete measures to fill the gap between minimal and professional digital competencies. The survey also uncovered pioneering good practices in the teachers' training program. Those university courses impart digital competencies very effectively, from which students could derive good practices to implement into their own teaching. The identified practices will be further examined in future research to provide students with greater opportunity to attend them and to outline opportunities for institutions to develop more courses that focus on digital competencies for teachers.

2.2 Polarization in public opinion

Opinion polarization is detrimental to society. It is linked to adverse effects such as increased hostility. These effects are exemplified in two ongoing crises: climate change and the COVID-19 pandemic. Opinions on those crises, combining survey research with data analysis from social media are studied by Graz University of Technology (TU Graz). We collected survey responses from 2560 people, accessed and linked the Twitter accounts of consenting respondents, and used a publicly available dataset of COVID-19-related tweets (CHEN et al., 2020). Additionally, we performed sentiment analysis and qualitative content analysis on the tweet content to validate comparability.

We find that opinions toward COVID-19 measures are more polarized and that older people are more in favor of COVID-19 prevention measures, whereas younger people show more support for environmental protection measures, thus suggesting that the two crises affect different social groups. Considering the content of social media data on COVID-19, we find that polarization is in line with the survey responses and that vaccination is a more polarizing subject than mask wearing and contact tracing (REITER-HAAS et al., 2022). We found divergent results depending on the respective social media platforms. Facebook users who do not follow the mainstream opinion and oppose environmental protection measures do not often share their accounts with us. In comparison, Twitter presents an information-based platform whose users are more open minded and closer to the scientific consensus. Accordingly, they share the mainstream opinion and provide their data with the scientific community (HADLER et al., 2022).

We conclude that data combination has merits in providing novel insights into polarization dynamics. Opinions that are openly expressed in surveys and content on social media platforms are linked. However, the platform's nature and personal biases play a vital role in this regard. Hence, more sophisticated methods are needed to disentangle the opinions embedded in social media content.

2.3 Cognitive and affective mechanisms of computer programming and computational thinking

There has been a growing interest in teaching students programming skills to prepare them for the demands of the increasingly digital society. Computational thinking (CT) and programming are often referred to as the literacy elements of the 21st century. This movement extends well beyond the need for more programmers. Consensus is growing that CT and programming are critical skills for all and are quickly becoming a new learning domain, on par with reading and mathematics. We lack sufficient understanding of how these skills can be best taught, assessed, and remediated. We also need to understand the affective and motivational mechanisms that influence the learning of CT and programming. This knowledge is crucial if we wish to change the current underrepresentation of women in CS and related degree programs. We study these topics in an ongoing collaborative project, combining methods from psychology/cognitive science from the Graz Uni domain and knowledge from CS from TU Graz, both of which focus on the relationship between CT and mathematical skills and on discovering the affective, emotional, and motivational factors that influence coding enjoyment, engagement, and flow.

In this larger research program we aim at validate a cognitive theory that defines a hierarchically organized taxonomy of skills involved in CT and programming, developing assessments for CT and programming and for their underlying skills, establishing links between cognitive processes in programming and other key learning domains like mathematics. We also seek to identify the affective, emotional, and motivational factors influencing coding enjoyment, engagement, flow, and the use of the acquired knowledge about the cognition and effect of programming.

3 Pilot projects

3.1 *Doing Data Science* Course

Data science is one of the most popular emerging domains, and it provides tools for 21st century jobs and for the most in-demand career options today (VAN LAAR et al., 2018). The importance of data science has grown with the increasing amount of available data, which is a precious asset for any organization. Motivated by the importance of data science, we design a course widely accessible to a broad range of students, with the goal to provide them with the fundamentals for setting up, managing, and conducting data science projects. The course is offered at UniVie to an interdisciplinary group of students within the Business Analytics, Data Science, and Digital Humanities master's programs.

One of the main challenges in designing this course is consideration for the different aspects of knowledge that students with different backgrounds have and to provide computer-science-related skills to professionals outside the field of computer science.

The Doing Data Science course (VELAJ et al., 2022) provides 6 ECTS presented the European Credit Transfer System. We present the steps of Cross-Industry Standard Process for Data Mining (CRISP-DM), which is a standardized process that describes and codifies the common approaches used by data mining experts. It is the most widely used analytical model in the industry (WIRTH & HIPP, 2000).

This class consists of different parts:

- Part I: Description and explanation of the main theoretical concepts
- Part II: Showcase of examples for data science projects
- Tutorial: Introduction to the data science tool KNIME
- Group work: Interdisciplinary student groups work together on a data science project

The KNIME Analytics Platform (BERTHOLD et al., 2007) is the open-source software for creating visual workflows with an intuitive, drag-and-drop-style graphical interface, without the need for coding.

From the students' answers, we concluded that the course was well designed and helped students from different backgrounds acquire skills for handling data science projects. The emergency remote teaching due to the COVID-19 crisis faced both positive and negative circumstances, facilitating access to the course material but making the project work phase more difficult. The KNIME software allows the students to overcome difficulties related to limited knowledge of programming languages, and the project work in heterogeneous groups is appreciated.

We think that the structure of the course described in the paper could also be used for engineering or computer science students as well as in a bachelor's course.

3.2 "*Digital Transformation*" Course: Teaching digitality for a broader audience

Two larger-scale university courses, *Digital Transformations* (up to 200 students from different disciplines each year) and *Communication and Interaction – Digital Education* (up to 80 teacher education students each semester) are offered at the Centre of Teacher Education in UniVie. Within the non-informatics focus of the project, the two courses address students from the teacher education field and students with a general interest in digital transformation.

Both courses are evaluated using both qualitative and quantitative methods, including pre- and post-surveys and online discussion groups. At the conference on Interactive Collaborative Learning (ICL), we presented a paper (POSEKANY, HASELBERGER, & KAYALI, 2022) assessing students' motivation using instruments informed by self-determination theory (SDT). According to feedback, the lecture series, Digital Transformations, "raised students' awareness to acquire competences in this field," and especially students with a low expectation of how useful digital media are gained a benefit from the course and increased their SDT parameters of perceived usefulness and productivity. Furthermore, "regarding perceived competence, the majority of the lower 75 % could report a clear increase." Finally, "students who will become future teachers and thus also role models for future generations increasingly came to realize that the utilization of digital media provided for greater autonomy."

Another paper (HASELBERGER, STEINBÖCK, & KAYALI, 2021), presented at the IEEE conference, Frontiers in Education, reports on the anchoring of MOOCs in the Digital Transformations lecture. We found that MOOCs can be used in a lecture and be open to the public at the same time. Online lecture sessions have been held to facilitate group discussions on MOOC content, which has been welcomed by students and, more importantly, "seem to foster critical discourse and reflection on the presented topics" from the MOOCs.

Over three iterations, the Digital Transformations course evolved from a classic frontal lecture series with little interaction in the room to a class fully implementing the flipped classroom concept. In WS2022, all lecture contents are presented in MOOCs, and students spend the sessions discussing and reflecting on the content.

A summary of the three years of experience with offering and creating MOOCs indicates a suitable means for a didactic design of topics from the broad spectrum of digital transformation for both university contexts and the general public. MOOCs are themselves digital artifacts, and the iMoox platform enables accessible ways to interact with the content in self-paced and self-controlled ways. The MOOCs are structured into five lectures, each containing two to four interactive videos, framed with scientific literature, and linking to additional online resources like research project websites, blog articles, or podcasts.

Finally, each MOOC contains a playful element to offer additional ways to engage with the learning materials:

(1) A maze allows for playful exploration of videos that have to be selected for a given task,

(2) An avatar is used to ask or utter critical questions or statements during the videos, and

(3) A video editing tool invites to creatively remix the MOOC's videos.

3.3 Interdisciplinary CS Curriculum Development

The TDT project plays a central role in the curriculum development at TU Graz. The project supports a larger effort in pivoting computer science from a purely technical focus to one committed to interdisciplinarity, diversity, and societal relevance. As part of this development, the Uni Graz and TU Graz have extended their teaching collaboration, initially resulting in the mutual integration of courses into the existing curricula and now in a new study program Computational Social Systems (CSS), which is described below.

To foster closer collaboration with other departments at Graz University of Technology, we have initiated plans for an extension curriculum in computer science for all students of engineering and natural sciences.

Teaching at the university level should be research driven. Thus, we also pay attention to research collaborations. We describe two joint research projects between the department of computer science (CS) at TU Graz and the departments of Psychology and Sociology at the University of Graz. These projects show how expertise from these areas can be combined to achieve results that neither discipline can achieve in isolation. Not described in detail within this document is another research initiative, the Graz Center for Machine Learning (GRAML), which joins researchers from the foundations and applications of Machine Learning in order to harness its full power in all application areas.

3.4.1 Computational Social Systems (CSS)

In 2021, Uni Graz and TU Graz launched a new English-language master's program for CSS. The program, designed for students with backgrounds in business administration, sociology, psychology, law, and CS, teaches skills to leverage data created in the digitized world to answer highly relevant questions for our digital society.

In the first two semesters, students attend lectures for interdisciplinary subject and those in CS or one of the application fields, depending on their background. They learn how to understand, classify, and predict the behavior of people using digital technologies and the analysis of data via statistical methods and machine learning. They then specialize in one of four focus areas.

Business Analytics: Students learn methods and technologies to create data-driven business models and decision support systems. They learn how to set up a Business Intelligence Concept to solve business management problems and discover how to manage large amounts of data.

Societies, Technologies, and Social Research: Students become familiar with the scientific discourse on the relationships among culture, social change, and technology. They learn how to conduct empirical research projects, including developing a research question, applying research methods, and presenting results.

Human Factors: Students engage with cognitive psychology and decision research. They conduct an empirical investigation on the psychology of human factors and address research topics like artificial life or complex systems modelling. Students become proficient in concepts and technologies of human-computer interaction, such as wearable devices.

Law and computer science: Students become familiar with fundamental and human rights theories and their application in the context of information technologies. They address legal questions on data protection and IT products and learn to develop and implement the legal requirements for an IT system in practical projects.

CSS emphasizes research-oriented teaching. Students with diverse backgrounds collaborate in seminars and conduct research projects to understand the current societal phenomena, such as the spread of misinformation.

CSS program was an overwhelming success. In the 2021/2022 academic year, 97 students from different backgrounds started studying CSS. The program is accessible to students usually underrepresented in STEM studies in Austria. Half are female, and 13 % have international backgrounds. The program offers an elective two-week summer school, which attracts significant interest from international students. This may explain the increase in international students to 37 % in the second year. CSS showcases that research-oriented teaching on topics relevant to society has considerable potential to attract students. The unique interdisciplinary environment at Graz enables us to bridge institutions and disciplines and provide advanced teaching for students with diverse histories and interests related to the digital society.

An extension curriculum in CS is currently being developed. The goal of the curriculum is to teach relevant CS skills to all students. The curriculum consists of an expandable basic set of courses totaling 30 ECTS. Its strong contribution to the employability of graduates is expected. Furthermore, the extension curriculum has the potential to facilitate entry into master's programs like Digital Engineering from other bachelor programs. The extension curriculum includes courses on the fundamentals and principles of CS in general, including programming skills, data science and machine learning, data management, data structures and algorithms, and security.

We are fundamentally revising the range of CS courses offered to non-computer scientists to accommodate an increasing number of increasingly diverse students. We will offer a set of courses suitable for students of different disciplines through adapted assignments that exhibit applicability to different application domains. We also pay attention to students' different levels of experience and language backgrounds. As CS skills become progressively significant for employees in many areas, this extension curriculum will allow students across disciplines to acquire these skills and increase their employability.

3.4 Development and research of the course *Facts, Fakes, and Algorithms*

Teachers' education significantly influences their use of digital media in future classrooms and positively affects their attitudes and self-efficacy expectations with regard to the use of digital media. This is relevant for the purposeful use and the didactically meaningful application of digital media in math and science lessons (DROSSEL & EICKELMANN, 2018). Therefore, it is highly important to implement high-quality digital media learning opportunities in the current teacher education. For this reason, at the University of Graz, a course for student teachers of mathematics and science subjects (biology, chemistry, physics) is being developed and researched in the paradigm of design-based research. The aim is to contribute to the professionalization of future teachers so that they can implement digitally transformed teaching practices. Within the framework of the course *Facts, Fakes, and Algorithms (originally in German)*, technical-pedagogical competencies as well as an understanding of digitality are addressed.

The aim of the iterative development process of the course is to design a learning-effective course that can be integrated into teacher training. At the research level, local, subject-specific, teaching-learning theories are formulated that can be deduced from the insights into the students' learning processes.

In developing the individual learning opportunities of the course, great attention was paid to address not only learning with digital media but also learning about digital media and about digital transformation. The entire development of the course is based on empirical findings. Competence goals were defined based on the existing competence models (BRINDA et al., 2019; MISHRA & KOEHLER, 2006; HONEGGER, 2021) as well as on the results of a curricula analysis of mathematics and science teacher education courses and the results of a survey of lecturers and students on attitudes and experience concerning digital media (MANDL et al., 2022). Results of these surveys, conducted at the University of Graz, indicate that student teachers have little experience with digital data acquisition and that their self-efficacy expectations in this area are rather low. They also show that students are offered very few learning opportunities in the area of learning about digital media during their teacher training and that students have little knowledge about dealing with (mis)information.

Based on these results, two focal points for the content of the course could be derived: Digital data acquisition and dealing with misinformation. Learning arrangements were developed using a theory-based approach on the basis of design criteria (MANDL et al., 2022a).

The global COVID-19 pandemic and the associated mathematical-scientific and social challenges provide the contextual framework for the teaching goals within the course. In the first part of the course, students work on questions about the (FFP2) protective mask. They collect CO_2 and fine dust values using an Arduino microcontroller.

In the second part of the course, the topic of misinformation is addressed, also in the context of the COVID-19 pandemic. In this context, the students work with the measurement data they have collected on protective masks and the currently held misconceptions about COVID-19. They learn to apply strategies to identify and debunk misinformation. The developed course design was implemented for the first time in summer semester 2022.

3.5 PLUS: Computer science for all

Teaching computer science (CS) is challenging, as is teaching other natural sciences. An additional aspect of difficulty is the lack of CS education in Austrian schools, and hence a huge lack of CS knowledge in society. Content-wise, the challenge comes from the expressiveness that computers and software provide: Given enough time, space (memory), and energy, we can compute anything that can be computed. Consequently, it is inherently challenging to teach CS, particularly to heterogeneous groups of students with vastly different backgrounds in computer systems. Students at the Paris Lodron University of Salzburg (PLUS) can pursue traditional CS bachelor's, master's, and doctoral programs. Furthermore, our courses are part of other, interdisciplinary curricula, e.g., the bachelor's program Digitalization-Innovation-Society (DIS), the Teacher Education in CS (TECS) bachelor's and master's program, the Data Science master's program, as well as a newly designed cross-faculty teaching program, CS Skills for All (CSSA), which provides CS content to all PLUS students. This requires us to respect heterogeneity while still ensuring that CS students develop a deep understanding of computer systems.

To this end, we try to unify CS education by focusing on the core principles that apply to (almost) any computer system. First, an effective course defines the core principles: *what* should be taught. It then breaks down complex techniques to their essentials and simplifies teaching and learning significantly. For example, a course could emphasize that everything on a computer system is encoded in an enormous number of bits. These bits, combined with the superfast, energy-efficient manipulation using basic arithmetic make computer systems so powerful. Essentially, students should develop intuition for computer systems, similar to the intuition they have of basic arithmetic and the grammar of a native language. The feedback shows that students are satisfied with our approach to teaching CS. In the remainder of this article, we briefly present three selected courses.

3.5.1. Problem Solving & Algorithmic Thinking

In this first-semester course[2] of the undergraduate DIS program and the CSSA program, students learn basic concepts to systematically solve problems, particularly thinking in an abstract, structured, and algorithmic manner. In addition, students develop an intuitive understanding of the fundamental costs and the limits of computation. All of these concepts are taught via carefully selected problem examples, games, and riddles. This approach has increased the popularity of the course among first-semester CS bachelor's students as well as TECS bachelor's and master's students. We have also based presentations and workshops of PR events on the materials from this course.

3.5.2. Introduction to CS & Systems

This course is part of the undergraduate programs of CS and DIS as well as the CSSA program. It introduces CS from a systems perspective and covers core principles using representative examples from basic computer architecture, compilers, and runtime systems. We use the Selfie system[3], an educational system that consists of a self-compiling C compiler and a self-executing/-hosting RISC-V emulator/hypervisor. Selfie is open source and enables us to discuss the core principles in a practical and systematic manner to foster the students' intuition of computer systems.

3.5.3. Distributed Information Management

The aim of this course[4] is to understand the core principles of database management systems (DBMS), e.g., data independence and declarative query processing. Students develop an intuition of (non-)relational DBMSs, distributed and parallel DBMSs, large-scale processing systems, and the challenges of the different systems.

2 Forster, S. & Sokolova, A. (2022). Problem Solving and Algorithmic Thinking. http://cs.uni-salzburg.at/~anas/psat.html, Accessed: October 15, 2022.

3 Kirsch, C. et al. (2015–2022). The Selfie Project. http://selfie.cs.uni-salzburg.at, Accessed: October 15, 2022.

4 Kocher, D. (2021–2022). Distributed Information Management. https://dbresearch.uni-salzburg.at/teaching/2022ss/dim/, Accessed October 15, 2022.

In the end, students can choose a system that fits their application context. During the course, students learn about selected systems in practical assignments, and we discuss the characteristics of specific systems in individual meetings. Our course is part of the undergraduate DIS program and the CSSA program, and it has increasingly attracted TECS students.

4 Conclusion

Based on the aim of the project developing new content, didactic methods, delivery methods, and sustainable implementation of the new concepts at Austrian universities by anchoring digital competencies in the curricula, the developed courses, *Computer Science for All* at PLUS, *Facts, Fakes, and Algorithms* at Uni Graz, *Digital Transformation* and *Doing Data Science Course* by UniVie, *Computer Science Education for Non-computer Scientists* at University of Innsbruck, and the Master's course *Computational Social Systems* by TU Graz and UniGraz are demonstrating contributions for finding solutions for the global challenges of the 21st century.

The development of MOOCs for the *Digital Transformation* course developed by UniVie and their integration into iMoox and *Computer Science for All* developed by PLUS are in line with the TDT project's main objectives, namely the development of didactic concepts. The courses also fulfill the objectives of developing and implementing teaching/learning offers of different granularity levels, from teaching/learning sequences over courses to the level of curricula. The results of research by UniVie showed that digital competencies should be included in the general basics of educational sciences – the curricula of teacher education. Although we are halfway through our project, we anticipate exciting outcomes, and for the next steps, the result will mostly work on the sustainability of the didactic context and courses.

5 Limitations

Due to the complex, interwoven, and dynamic nature of the project, this study has a limitation of presenting all activities carried out to achieve the project's objectives in this paper. Due to the page limitations of this paper, all actions have been briefly described. The TDT website has the detailed information and publications.

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