ETH zürich

Educational Development and Technology

ETH Learning and Teaching Journal

Vol 4, No 1, July 2023

Educating the next generation

Editors

Michèle Gemünden
Pia Scherrer
Benno Volk

LET

Contents

Editorial

The current issue of the ETH Learning and Teaching Journal gives prominence to teaching and learning initiatives at ETH which focus on the theme of "educating the next generation". One of the central characteristics of higher education is its orientation towards the future: today's students will significantly contribute to shaping the world of tomorrow. This also means that what and how students learn today influences the way in which they will be able to make a positive contribution to the future. Discussions on what students are to learn in order to meet the challenges of the 21st century[1] mention a wide range of skills and competencies including leadership and collaboration skills alongside data, ethics and multicultural literacies and character traits such as self-direction and mindfulness (The Glossary of Education Reform, 2014; Ehlers & Kellermann, 2019; Genner, 2019; ETH Competence Framework, 2023)

The contributions to this issue explore different aspects of educating the next generation of students at ETH. Some articles report on specific courses, others discuss educational strategies or identify a specific skills set, and some focus on the institution as a whole:

Serena Graziosi et al. report on establishing a course which aims to educate the next generation of engineering designers in view of recent advancements in digital fabrication.

Ludovic Räss et al. showcase how non-computer science students learn to conduct numerical research.

Dominik Stämpfli et al. present a course framework which addresses the changing professional requirements in the pharmaceutical profession and helps students develop decision-making and effective communication skills.

Fritz Kleinschroth's contribution reports on creative and collaborative ways of framing and solving problems in a course on urban ecological research.

Caroline Welte, Adrian Gilli and Jordon Hemingway promote networks among doctoral students to help them successfully proceed through their doctoral studies.

While Joan Oñate Narciso and Zarah Walsh-Korb argue for cross-disciplinarity in the natural sciences, Katharina Fellnhofer and Ursula Renold make a case for professionally training the use of intuition in order to master complex and uncertain situations.

Barbara La Cara, Michèle Gemünden and Barbara Koch-Kiennast report lessons learnt from developing and implementing a competence framework at ETH.

Zurich, July 2023

Michèle Gemünden, Pia Scherrer, Benno Volk

Issue editors

[1] https://curriculumredesign.org/our-work/papers/

Bibliography

ETH Competence Framework (2023). Available online: https://ethz.ch/content/dam/ethz/main/eth-zurich/organisation/stab-rektor/eth-talent/eth-competenceframework-fulltext-en.pdf

Ehlers, U.-D. & Kellermann, S.A. (2019). Future Skills – The Future of Learning and Higher education. Results of the International Future Skills Delphi Survey. Karlsruhe. Available online: https://www.researchgate.net/publication/332028491_Future_Skills_-_The_Future_of_Learning_and_Higher_education_Results_of_the_International_Future_Skills_Delphi_Survey

Genner, S. (2019). Aufwachsen im digitalen Zeitalter: Kompetenzen und Grundwerte. Eidgenössische Kommission für Kinder- und Jugendfragen. Available online: https://ekkj.admin.ch/fileadmin/user_upload/ekkj/02pubblikationen/Berichte/d_2019_EKKJ_Bericht_Digitalisierung.pdf

Glossary of Education Reform (2014). Available online: https://www.edglossary.org/21st-century-skills/

Advancing design for Additive Manufacturing Education: A focus on computational skills and competencies

Serena Graziosi[1]

Department of Mechanical Engineering, Politecnico di Milano, Milano, Italy

Jun Wu[2] **and Zjenja Doubrovski**[3]

Department of Sustainable Design Engineering, TU Delft, Delft, The Netherlands

Nicholas Meisel[4]

The Pennsylvania State University, University Park, Pennsylvania, USA

Martin Schütz[5] **and Tino Stankovic**[6]

Engineering Design and Computing Laboratory, Department of Mechanical and Process Engineering (D-MAVT), ETH Zurich, Zurich, Switzerland

Abstract

Recent advances in digital fabrication are expanding the limits of fabricable real-world designs. Additive Manufacturing (AM) technologies allow exploring unconventional design solutions across all scales and fields in fundamental science and engineering practice. Over the past years, this possibility has established AM and Design for AM (DfAM) as integral parts of engineering design curricula. Educators and researchers in engineering design are thus highly interested in investigating how designers should be best educated to follow, utilize, and actively participate in this advancement in digital fabrication. However, despite this growing interest, studies describing teaching experiences focused on DfAM are still limited. Besides, almost no studies report on how DfAM education affects students' further academic studies or professional careers after exposure to the topic.

To address this gap and contribute to *educating the next generation of designers*, the paper conducts an online follow-up survey with alumni of two editions of the Computational Design for AM Summer School in an attempt to answer how the acquired knowledge, skills, and competencies impacted their studies, research, and professional careers in a long-term after their participation in the course. The discussion is augmented with the results of two supplementary surveys on the teaching experiences and students' feedback performed right after each summer school edition. Results show that participants are conscious of the potential long-term impact of the lived educational experience. Besides, the school's multidisciplinary environment and the implemented problem-based approach have been fundamental to creating an engaging and valuable learning experience.

[1] serena.graziosi@polimi.it
[2] J.Wu-1@tudelft.nl
[3] E.L.Doubrovski@tudelft.nl
[4] nam20@psu.edu
[5] martin.schuetz@mavt.ethz.ch
[6] tinos@ethz.ch

Introduction

Additive manufacturing (AM) technologies continuously evolve in processable materials, resolution, printing volumes, and quality (Leung et al., 2019; Rosen, 2014; Thompson et al., 2016). This evolution extends design boundaries and pushes the development of cutting-edge and high-added value ideas in various fields, from biomedical to architecture, from aerospace to product design, and computer graphics. Designers can now explore and develop tailored and advanced solutions by exploiting the potentialities of these technologies at the design level. Functional integration, multi-material printing, local and multi-scale tuning of properties, and highly complex organic shapes are only a few of the design opportunities available nowadays (Leung et al., 2019). However, it is worth noting that these design opportunities also extend current design paradigms (Gao et al., 2015; Rosen, 2014, 2016). The possibility, for example, of designing metamaterial (or architected materials) is opening new design scenarios beyond the established concept of material selection (Greer & Deshpande, 2019; Montemayor et al., 2015). The proper exploitation of such a wide range of opportunities calls for a new mindset that is strongly multidisciplinary and capable of mastering interlinked requirements. To create this mindset, computational and algorithm-based design strategies can contribute fundamentally (Leung et al., 2019; Liu et al., 2018; Rosen, 2016). Indeed, considering the increase in design complexity, they are essential to support designers in exploring the design space, modelling complex and multidisciplinary phenomena, and enabling the advanced control of the fabrication process.

The innovativeness of a 3D-printed solution relies on the ability of designers to successfully establish a trade-off among material properties, digital modelling, and the control of the manufacturing process while exploiting a wide range of design opportunities. In response to these design opportunities, a comprehensive survey of DfAM in higher education was conducted recently (Borgianni et al., 2022) to emphasize and promote the need for adopting DfAM into standard engineering design curricula. The survey also shows that most approaches to teaching DfAM use inductive problem- and project-based learning pedagogies, originally suggested by (Williams & Seepersad, 2012). There (Williams & Seepersad, 2012) it is argued that relying on smaller practical problem-solving tasks focused on knowledge acquisition or on one larger open-ended project-based task involving teamwork, knowledge application, and synthesis encourages students to comprehensively explore the possibilities and limitations of AM technologies. To support such courses, the teaching staff serves as course instructors, tutors and facilitators. For example, the work (Thomas-Seale et al., 2022) reports on the diffusion of DfAM principles in teaching through a project-based learning approach: it positively impacts students' consciousness about their level of knowledge, self-efficacy, and capabilities in addressing a DfAM challenge, i.e., an open-ended design project. Similar to standard engineering design curricula (Dym et al., 2005), the students benefit from the DfAM challenge problem, which reflects the design practice and also, at the same time, frames the overall learning objectives (Williams & Seepersad, 2012). DfAM courses can use a hybrid model between a standard classroom approach and problem-based learning (Diegel et al., 2019). The work reports that the inductive approach to teaching based on project-based learning contributes to knowledge acquisition and overall course satisfaction, in contrast to standard classroom practices relying primarily on memorizing the course material. The works from (Diegel et al., 2019) and (Williams et al., 2015) also report a team-based course organization to the DfAM design challenge. Such informal learning environments are set to mimic real-life professional situations (Sawyer, 2005) and prove beneficial for motivating students and enhancing their skills in leadership, collaboration, communication, and innovation (Williams et al., 2015). To implement project-based approaches, it is also fundamental to provide students with suitable methodologies and tools to push them to think outside conventional manufacturing paradigms, as demonstrated in academic and industrial teaching environments (Blösch-Paidosh & Shea, 2021, 2022). For example, the study (Prabhu et al., 2020) investigated how the educational content of a DfAM course affects the students' use of DfAM in the engineering design process. The study concludes that to push students to exploit AM in the design, future teaching practices need to include concepts emphasizing the capabilities and opportunities of AM rather than focusing on AM limitations. The teaching modality can also play a relevant role. A recent study (Schauer et al., 2022) has highlighted that the virtual teaching modality could give students more "freedom" to express their creativity when asked to implement DfAM principles because in-person suggestions could limit their inventiveness. The study also showed that the adoption and use of DfAM principles are almost equal when comparing virtual and in-person environments and concluded that more research is required to pinpoint the exact sources behind the creativity block occurring in in-person environments.

To explore how to train the next generation of designers for AM, the authors have designed and offered an international summer school on Computational Design for AM. This paper shares the educational drivers that pushed the authors to organize the summer school and summarizes the feedback collected from the participants. The summer school is intended for selected international master's and PhD students and aims to explore and apply the potential of computational-based strategies in Design for Additive Manufacturing (DfAM). As shown in the relevant literature (Leung et al., 2019; Liu et al., 2018; Rosen, 2016), computational and algorithm-based design strategies are essential to creating a mindset capable of designing for AM; they help designers exploit AM's potential at the design and fabrication levels. Successful implementation of these strategies enables the exploration of the design space, mastering interlinked requirements, stimulates the modelling of complex and multidisciplinary phenomena, and supports the advanced control of the fabrication process. The IDEA League alliance (https://idealeague.org) has promoted and supported the two editions of the school (i.e., 2020 and 2021). The school has so far taken place online due to the COVID-19 pandemic. The authors also served as course instructors, tutors, and facilitators for both instances of the summer school.

The paper aims to reflect on these two school editions and investigate how DfAM education has affected participants' academic studies and professional careers after being exposed to the topic. Insights are derived based on an online follow-up questionnaire shared with the summer school alumni with a time lag of at least 1 year after the summer school ended. The aim of preparing the questionnaire is twofold: (1) to identify issues with previous offerings and propose new actions for improving the educational experience and (2) to understand whether the acquired knowledge, skills and competencies have influenced participants' careers in the long term. The motivation stems from the fact that almost no studies report on how DfAM education affects students' further academic studies or professional careers after exposure to the topic. Based on the questionnaires' results, this work draws conclusions outlining how to advance DfAM education, especially as it relates to short-form, online offerings. The results and findings are augmented with two additional supplementary questionnaires shared with the school participants immediately at the end of each school edition (in 2020 and 2021), which report on general course satisfaction.

The Computational DfAM Summer School

To contribute to disseminating DfAM principles to the next generation of designers, the Computational Design for AM summer school was conceived starting from the following premise: teaching DfAM means stimulating the creation of a design mindset ready to exploit the maximum potentialities of AM technologies in every phase of the process, from the idea generation to the post-processing. Hence, the summer school was conceived to train students and young researchers in exploring and applying the potential of computational-based strategies in DfAM through dedicated learning sessions and team working activities to create a problem-based learning context.

The following learning objectives were established: 1) explain the fundamentals and challenges associated with AM technologies and computational DfAM support methods; 2) apply the digital workflow (scanning-computational design-digital fabrication) for customized product design and state-of-the-art computational design tools and methods to DfAM; 3) identify appropriate and innovative application scenarios for AM.

The summer school was organized as an intensive two-week combination of lectures, teamwork, and project-based performance assessment (Fig. 1). In addition to the students from universities of the IDEA League alliance, the summer school involved students from the ASPIRE League (www.aspireleague.org), the Design Society (www.designsociety.org) as a worldwide community of researchers in the field of engineering design, and in 2021, students from Ashesi University in Ghana. Summer school participants were 34 in 2020 and 36 in 2021. For team working sessions, they were divided into groups of 5-6. Considering the broad relevance of AM technologies in multiple disciplines, students' backgrounds ranged from mechanical, materials, biomedical and aerospace engineering to industrial design and architecture. This heterogeneous mix of backgrounds was expected, considering the broad interest in AM technologies from different industrial fields and contributing to an added value for the school learning experience. In light of this heterogenous mix, a design challenge that could be addressed by all students independently from their background was conceived, as explained later in the text. Since the students' backgrounds were known before the beginning of the school, teams were organized to balance the knowledge and necessary skill sets, facilitate diversity, and manage teamwork hours with members in different time zones (Fig. 1). Indeed, each summer school edition has seen participants from at least two different continents. For example, the main criteria used are the following. We considered the gender balance, ensuring, when possible, that female participants in both editions were homogeneously distributed. For example, in the 2020 edition, 2 female members were included per team wherever possible. The second criterium was time-zone differences. In particular, we guaranteed that, for each team, only one student at most had a significantly different time zone to make the management of teamworking activities more feasible (e.g., the students could work in series). Where possible, we also avoided including too many students from the same university on each team. At the same time, we tried to achieve an equal distribution between students from PhD and Master programmes. It was also crucial that each team could count on at least a basic level of digital modelling, for example, by involving a team member with expected proficiency in using CAD tools based on the declared background.

In its online format, the summer school relied on Microsoft (MS) Teams as the communication environment, also serving as the course content management system. The teams were assigned to virtual rooms that could be visited by course instructors at any time during the school to initiate live discussions. During the school, groups organized themselves further into individual sub-teams with dedicated communication channels and meetings to facilitate the work over different time zones. The other means of communication include chatting over MS Teams and direct emails to course instructors.

The lectures were divided into four thematic blocks to cover core aspects of computational design for AM (Fig. 1). These blocks were: an overview of DfAM possibilities, multi-material fabrication, generative design, and metamaterial design. To facilitate the online teaching modality, the blocks were based on the flipped classroom approach as a combination of recorded sessions with lectures from the organizers and invited live talks from other researchers and experts in the AM field. Recorded lectures were made available to summer school participants about one week before the start. These lectures gave students the necessary background knowledge to be active participants during the related guided studio sessions, organized one for each of the four thematic blocks. This setup allowed students to receive immediate support and supervision for their projects by interacting informally with the course organizers. Since the summer school required the application of several computational tools, these guided studio times were also used for live tutorials, as well as explanations of programming scripts and solutions that were pre-prepared by the organizers to be used by the students during the school. Thus, students received direct support and live feedback from the course instructors during teamwork, breakout sessions, and guided studio times. At every school stage, at least two instructors were available to support the teams' work.

The central element of the summer school was the DfAM challenge, i.e., an open-ended design project introduced on the first day of the summer school (Figs. 1 and 2). In both instances of the summer school, the design challenge involved a redesign for AM of preselected parts and components of a bicycle. Students were asked to select at least one subsystem of the bike among those provided to them and implement the DfAM principles learned during the school. They were supplied with digital models of the following subsystems: the frame, the wheel, the seat post, and the fork with the front suspension. During the summer school, the participants learned the necessary theoretical background and skills required to solve the design challenge using computational methods and tools.

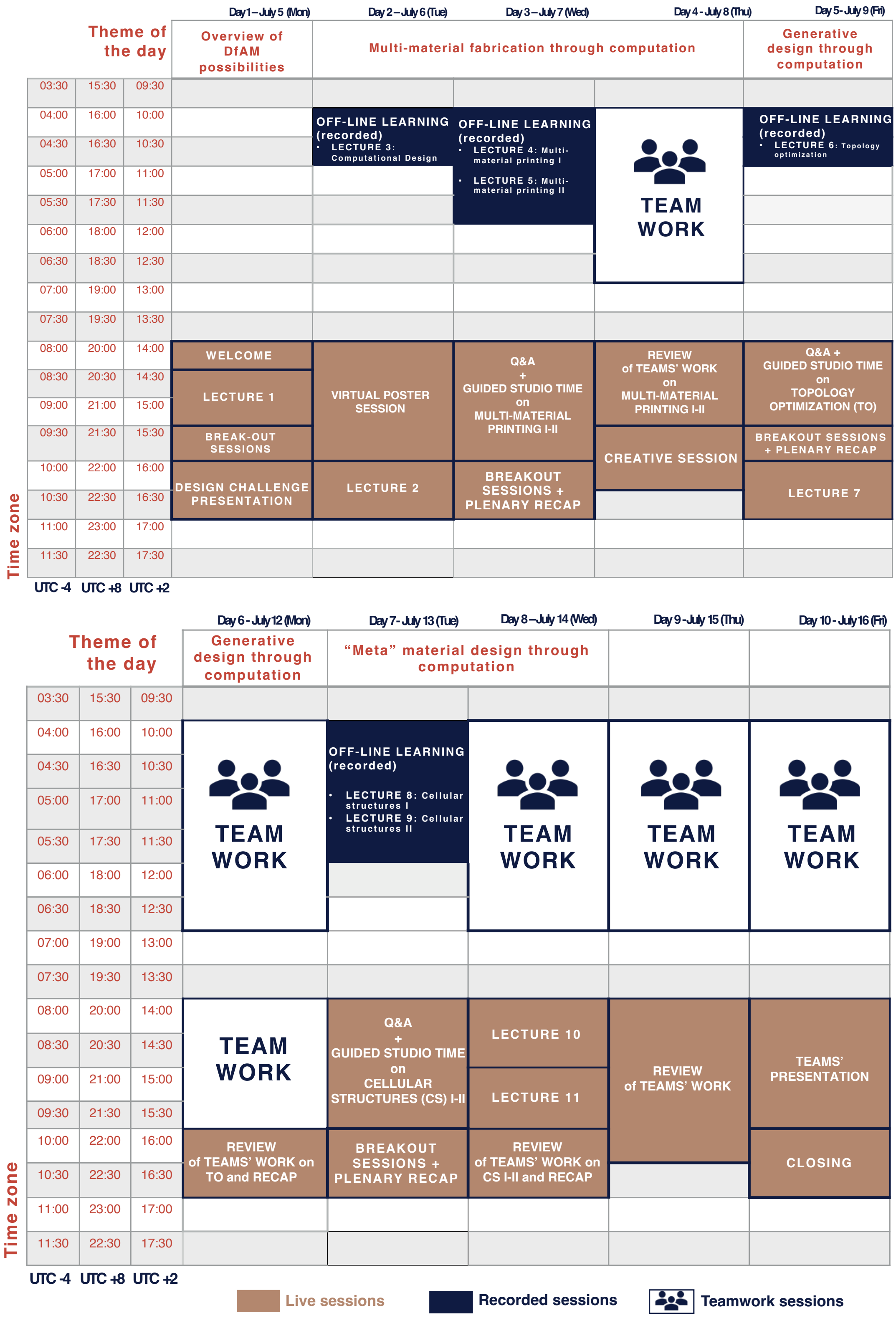

Figure 1: The summer school structure (2021 edition). It is based on the flipped classroom approach as an intensive two-week combination of: a) interactive live sessions involving lectures, guided studio

times, reviews and project-based performance assessment; b) recorded sessions made available one week before the summer school starts; c) teamwork. A "theme of the day" is identified for those days involving lectures, guided studio times and project reviews. The time zone difference is highlighted to make participants aware of this issue.

The challenge was addressed as a part of their practical work throughout the course. To facilitate the course, a design expert in the field of bicycle design served as a course instructor for the whole school duration. This expert has instructed participants concerning the main design requirements to be considered for redesigning these subsystems. As anticipated, considering the heterogeneous background of the participants, the bike design challenge was considered a topic general enough to be relatable by all participants, at least in the role of end-users.

Apart from the design challenge culminating on the closing day with final presentations of the designs produced by each team (Fig. 1), students were also asked to introduce themselves individually in a virtual poster session using a 30-second-long pre-recorded video. The breakout sessions also allowed students to share their intermediate outcomes with the course instructors and discuss other research and course-related topics.

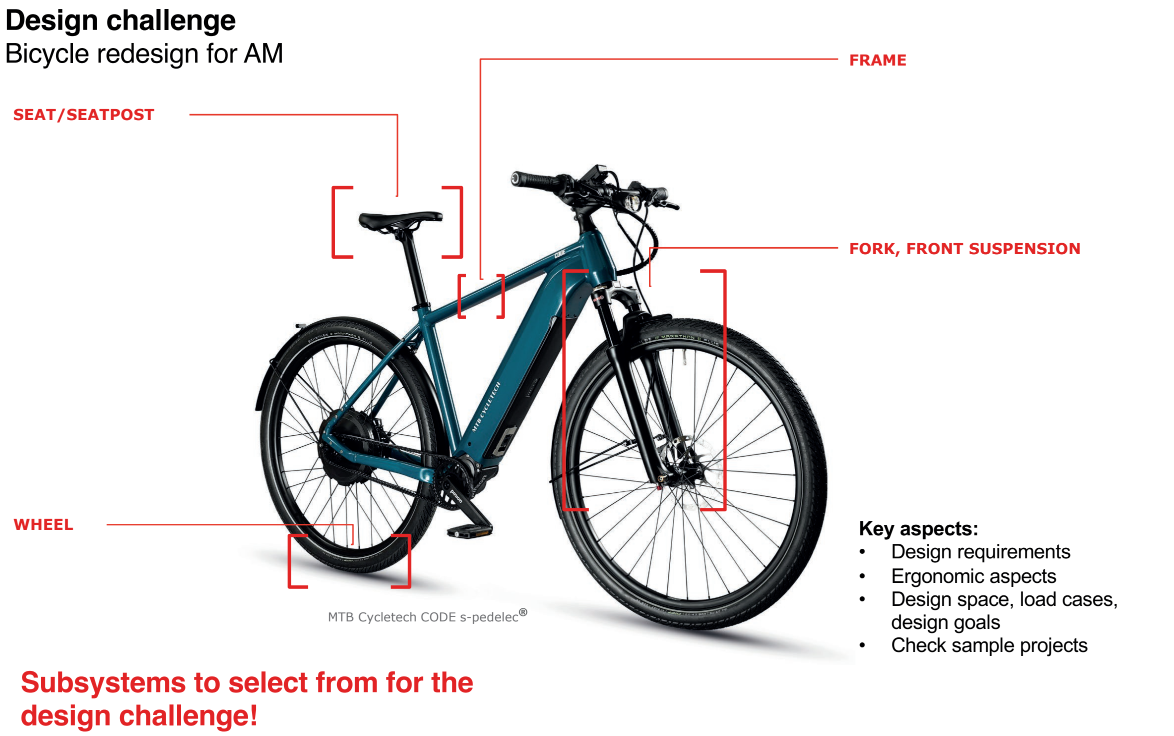

Figure 2: DfAM design challenge project showing the four possible subsystems of a bicycle students could select to be redesigned for AM.

The assessment is project-based and performed by all course instructors using 0-5 grading marks. Teams are evaluated for the quality of their presentation, innovativeness of the idea, printability and technical feasibility of the proposed solution, aesthetics and ergonomics (if applicable), and effectiveness of the implemented/foreseen design process. Given 6 evaluators (course instructors) and 5 categories, each team could score maximally 150 points. The three best teams were awarded a digital voucher from an international 3D-printing service.

Methodology

After completing the two summer school editions, the invitation for the follow-up questionnaire (for details regarding the questionnaire, please see Appendix) was disseminated to previous participants via email. The questionnaire implemented online using Microsoft Office 365 Forms focused predominately on (1) how their perceptions of the summer school have changed since their initial participation and (2) how the content from the summer school has or has not proven relevant for their work in the intervening years. This questionnaire consisted of 15 questions, with a mixture of quantitative, categorical, and free responses. Such a mixture of questions is characteristic of engineering design research to support studying various factors whose behavior would be difficult to characterize unless a combination of approaches is used (Blessing & Chakrabarti, 2009; Tashakkori et al., 1998). Thus, the obtained data allows us to capture the diversity of views among the participants in describing insights, opinions, and explanations regarding the summer school, with the possibility of obtaining unexpected results. The survey invitations were sent using the email addresses students used to register for the course each year and based on the email addresses provided at the end of each course by the students who wished to maintain long-term contact with the organizers. Additional email addresses were obtained using connections between alumni and the organizers through professional social networks.

In addition to the follow-up questionnaire, two supplementary questionnaires were prepared in 2020 and 2021 by the IDEA league for details regarding the questionnaire, please see Appendix). The questionnaires followed mixed question formulations similar to the follow-up survey and were disseminated via email. They were created to gain insights about various aspects of the summer school involving the individual lectures, contributions of practitioners/supervisors, design challenge and network building, and organization of the summer school (e.g., the online setup of the program, the balance between lectures and practices, course description). The rating was on a scale of 5, from “not at all satisfied” (1) to “extremely satisfied” (5). There were three open questions regarding: the most enjoyable part of the program, comments/suggestions for the design challenge, and comments/suggestions for improvement of the program. The survey invitations were sent to participants on the last day of the school using the email addresses students used to register for the course each year.

All the surveys were conducted anonymously, and the results are presented such that tracing individual answers to a particular survey participant is not possible. The research in this work has been approved by the ETH Zurich Ethics Commission.

Results

For the follow-up questionnaire disseminated to alumni of the summer school, a total of 23 responses were collected, denoting an approximate response rate of 33%. Participants were contacted via email or via social media. Responses rates were similar for each edition of the summer school, with 10 responses from participants from the 2020 version and 13 responses from participants from the 2021 version. Respondents were mainly at the PhD level of their studies (n = 57%), with other respondents from the MS (n = 22%), Postdoc (n = 9%), or Professional (n = 13%) levels. When asked about their initial motivation for joining the summer school, most respondents selected that they had a previous passion for AM that they wished to leverage in the summer school (n = 52%). Other respondents instead indicated that they were not already experts in AM and, as such, wished to use the summer school to gain these skills (n = 35%). Further, after completing the summer school, most respondents claimed that the program was either the most engaging online learning experience they have participated in (n = 43%) or similarly engaging compared to their other online experiences (n = 43%). Only 2 respondents selected that they felt unengaged by the online learning format of the summer school. Respondents who reported engagement with the content attributed it to (1) the practical and relevant nature of the topics being presented, (2) the responsiveness of the faculty, and, most commonly, (3) the inclusion of the group-centered design challenge. Students noted that the inclusion of the group work allowed them to interact with their peers in a way that may not often happen in online educational spaces. With respect to the course performance assessment, in 2020 the average score was 106.8/150 with the median of 105.5, whereas for 2021 the average performance was 112.4/150 with the median of 109.5.

Regarding the ultimate relevance of the summer school content, responses were relatively dispersed, with some participants saying that the AM topics from the school are relevant to projects they are currently engaged in (*n* = 39%), while others responded that the topics were relevant, but not being used in their current project (*n* = 26%). The remaining respondents believe that the topics are not currently relevant to their work (*n* = 26%). However, when looking into the future, respondents appear more optimistic, with 14 (61%) believing the topics from the summer school to be relevant to the long-term trajectory of their career. Seven respondents were unsure of future relevance, with only one respondent believing that the content was not relevant for their long-term career. In the follow-up open-ended question (yes, could you explain for which purpose (e.g. for career advancement, for future projects)?"), out 15 responses, 3 clearly indicated career advancement, while the reminder commented with either future projects or to obtain new skills in AM. When asked to assess the relevance of individual topics from the summer schools on a scale of 1-5 (5 being of most relevance), participants rated AM's overall design possibilities (i.e., "free complexity") the highest relevance with an average of 4.13/5. The design challenge was also viewed favorably with 3.57/5. More specific topics were viewed to be less relevant, including topology optimization with averages 3.30/5, lattice structures 3.22/5, and multi-material printing 2.70/5.

The supplementary questionnaires in 2020 and 2021 received 30 responses from 34 students and 31 responses from 36 students, respectively. The results for the closed questions sections showed that the rating of individual lectures was consistently high for all lectures, with an average of 4.44/5 (2020) and 4.45/5 (2021). The organization in both years was rated very positive as well, with the second run being rated somewhat higher. The questions regarding the organization and the rating in both years can be seen in Fig. 3.

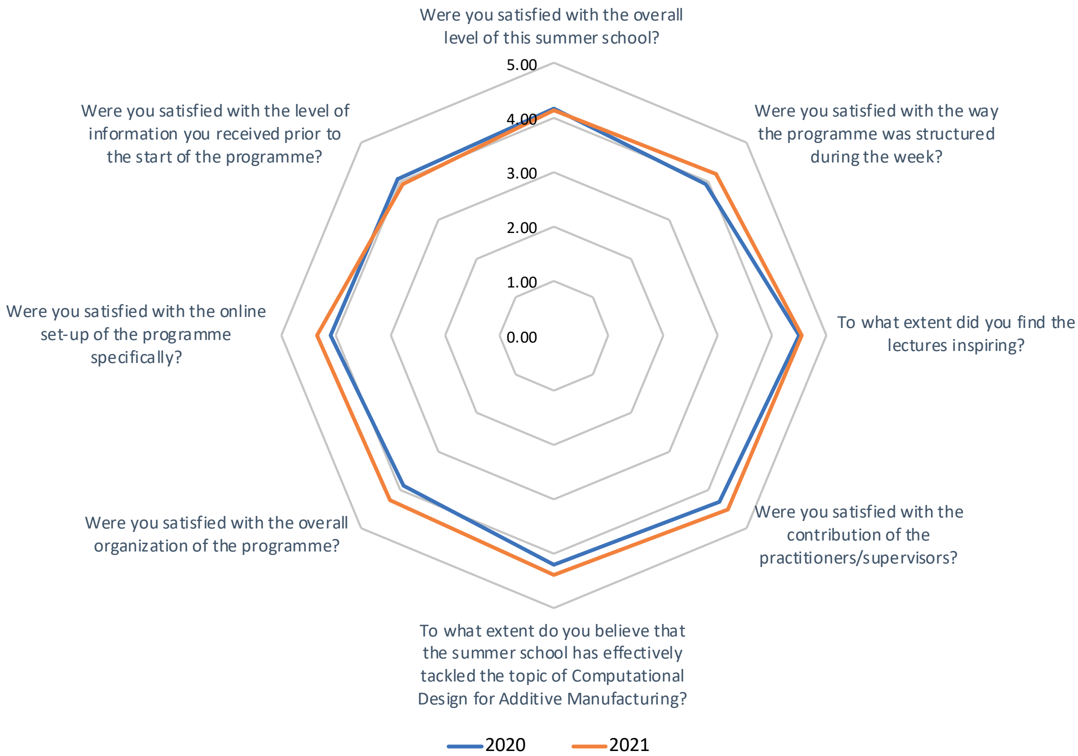

Figure 3: Responses for the closed questions sections of the supplementary surveys in 2020 and 2021.The results in the figure show the average value per question.

An important question is, “To what extent do you believe that the summer school has effectively tackled the topic of Computational Design for Additive Manufacturing?”. On this one, in 2020 and 2021, the average rating was 4.2/5 and 4.39/5, respectively. By responding to the question “How did you work for the design challenge? (a single-choice question, 1 to 5 scale, 1 - Always with my group and 5 - Always individually), the results for 2020 suggested the vast majority worked with a balance between individual and teamwork, 14 out of 30 students chose 3, and 12 students chose 2. Further, 2 students worked always with the team. The 2021 results spread over from 1 to 5, with slightly more towards 1 than towards 5. 7 out of 31 students worked always with the team, 5 students however worked always independently. In the open question regarding improvement of the program, one of the respondents who chose 5 (i.e. Always individually) showed frustration with the group forming. In contrast: in the open question about the most enjoyable part of the program, aspects that frequently appeared in the answers include: the variety of topics as well as the format of teaching, e.g., recorded and live lectures, meeting and working with people from other disciplines, and the design challenge (in particular the teamwork and as a practice of the theory). Students also frequently mentioned “new perspectives on AM”, “more information of the possibilities of AM”, “thinking about the design specifically for AM”, “the possibilities of AM at different scales”, “how these technologies/ knowledge can be used to design the parts”, “how to think for creating new designs”, and “new tools and software”.

Regarding the open question on improvements of the program, in both years, there were multiple comments and suggestions on tutorials for learning practical tools and software, regarding, e.g., topology optimization and parametric modelling of lattice structures. The frequent mention of practical tools and software suggests that the wish to learn practical tools was common among many students.

Other comments and suggestions touched upon, e.g., the design challenge and group formation, the prior knowledge for entering the summer school. The diversity of student backgrounds is common in master/PhD education. In the multi-disciplinary field of DfAM, this diversity becomes more pronounced. This was acknowledged by students as seen in the “most enjoyable parts”. Individual students who were less familiar with AM and computational design may have experienced more challenges in the program.

Discussion

A number of relevant insights can be derived from the questionnaires (i.e., the follow-up and the two supplementary ones). First, the fact that for a number of participants, some of the topics learned are not currently relevant in their professional careers was to be expected. Some industrial fields with a long tradition in computational design, such as the aerospace and bio-medical industries, which attempt to utilize the design freedom enabled by AM beyond just streamlining their manufacturing, are more ready than others to adopt AM technologies (Prabhu et al., 2020). Indeed, this is confirmed by the survey participants working in architectural design stressing the immediate relevance of the topics learned for their careers. However, the fact that, overall, participants have seen the relevance of the learned topics from a long-term perspective means they understand the potential of the insights discussed. It is also worth noting that the instructors’ lectures, particularly those of the invited speakers, were intentionally strongly research-oriented, with a focus on the long-term implications of design. The idea was to make participants aware of the ongoing developments and wide range of possibilities that can be explored thanks to the design freedom allowed by AM technologies. Besides, since there were PhD students among the participants, a further aim was to provide them with suggestions for their research. Hence, although these insights may not be immediately relevant in a short-term scenario, especially in specific industrial fields, participants have instead caught their potential in a long-term view. This consideration matches appropriately with the other results obtained from the follow-up questionnaire. Indeed, the design challenge was considered relevant for their career because they may now be involved in team- project-based activities. On the contrary, the multi-material printing topic was considered less relevant than, for example, topology optimization because the former is still a pioneering field considering the reduced number of commercial printing technologies that can enable it. In general, we observe the trend that more specific topics were perceived as less relevant in favor of the design challenge, which also encompassed these topics to a certain degree but in the context of a specific design task. The affinity of students to participate in a concrete design challenge in AM, rather than specialized isolated topics, has also been recognized by others (Diegel et al., 2019): the complexity of the task that drives the course requires teamwork, hands-on experience, and application of a previously acquired knowledge, and contributes to the acceptance of project-based classes. Thus, framing specific topics more closely to the design challenge should increase their relevance for summer school participants. Similar findings to (Diegel et al., 2019) are reported in (Thomas-Seale et al., 2022) and (Williams et al., 2015) stating that students favor participation in hands-on environments in comparison to standard lectures. Most of the responses to the open-ended Question n°15 stress the importance of teamwork by stating that it boosted their motivation and allowed them to discuss and clarify the contents of the lectures. They also felt engaged in the design challenge and appreciated the fact that the set-up was based on real-life activities. These experiences correlate strongly with findings that informal learning environments that mimic real-life professional situations directly influence the knowledge created (Sawyer, 2005) and prove beneficial to reach the teaching outcomes of a DfAM project-based course (Williams et al., 2015).

Concerning the results of the supplementary questionnaires, an interesting aspect to highlight is that based on the open comments provided by the participants, a more practice-based program was expected with instructions on how to use specific software programs properly. Despite the clarification provided to manage this expectation in the second run of the summer school, this was still a request for a small number of students. Although practical indications were provided during the guided studio times, the limited time available was not enough to provide in-depth training on using a specific software tool to students with different backgrounds. Besides, the intention was to offer them an overview of the main tools available rather than concentrating the school only on one software platform. This decision was also taken because there is still not a unique, comprehensive platform to fully exploit the design freedom AM technologies provide. However, to limit this potential barrier to students' creativity, dedicated actions could be undertaken in future editions of the school, for example, by providing some pre-recorded tutorials. In this respect, it is also important to clarify once again that instructing participants on the use of a new software is not a priority in terms of learning objectives. As underlined, the priority is to show participants the solutions that could be developed now, and potentially in the future, thanks to the continuous innovations in 3D modelling tools for AM.

The supplementary questionnaires have also stressed several findings regarding the summer school. First, the average rating of 4.2/5 and 4.39/5 (in 2020 and 2021, respectively) regarding the question "To what extent do you believe that the summer school has effectively tackled the topic of Computational Design for Additive Manufacturing?" (Fig. 3), confirmed that the sub-topics covered in the summer school match the expectation of the students. Furthermore, the performance assessment of teams involving, presentation quality, idea innovativeness, printability and technical feasibility, aesthetics and ergonomics, and effectiveness of the implemented/foreseen design process achieving rather high average and median scores in both 2020 and 2021, confirm good adoption of relevant AM knowledge and skills. Second, the responses in the surveys also underlined the importance of creating a collaborative and multidisciplinary environment as a fundamental element for creating an engaging learning experience. With AM technologies, this multidisciplinarity is favored, considering how strongly interlinked design decisions are with those related to the material and the processing technologies. Hence, it is fundamental when planning an educational event focused on DfAM to promote the presence of a multidisciplinary audience. And third, in their responses, the students highlighted teamwork and networking as elements of the course they truly enjoyed.

They also stress the need to organize the teams with equal levels of multidisciplinary skills required to tackle the design challenge. In 2021, 5 students however worked always independently, and this indicates that 1 or 2 teams didn't function a "team".

Overall, the online modality has been demonstrated to limit students' engagement, even if the quality of the educational experience, thanks to the action put in place to stimulate teamworking, has moderately counterbalanced this issue. However, an aspect to underline concerning the online modality, particularly if compared to an in-person and residential modality, is that participants may have been distracted by other parallel obligations related to their daily activities, which may have prevented them from devoting themselves entirely to the program.

Conclusions

This paper aims to advance the knowledge concerning the education of the next generation of designers by discussing the insights collected from a two-edition online summer school on Computational Design for Additive Manufacturing. It describes the structure of the school and the primary educational targets considered as a reference to design the educational experience, from selecting the school's main topics to organizing the participants' teamwork.

Through the results collected from an online follow-up questionnaire and two supplementary questionnaires made available right after the end of each summer school edition, insights were derived starting from participants' responses. Results show an overall positive evaluation of the offered educational experience for what concern the organization, the topics discussed and the participants' involvement. Specifically, the project-based approach has been demonstrated to be appreciated in the responses collected right after the school and in those collected from the follow-up questionnaire. It has indeed been considered a relevant experience also in a long-term perspective. Hands-on training is also an essential element of the learning experience. As the summer school focused on computational design aspects, more training on software applications was expected. Also, creating a multidisciplinary learning environment, i.e., enrolling students with different backgrounds, has been revealed to be a fundamental aspect of promoting knowledge contamination. This insight emerged from the analysis of the open comments provided by the participants. As a final consideration, the online modality has been essential in dealing with the impossibility of organizing in-person events. However, it is still considered not as engaging as the in-person modality.

We can conclude that, overall, the insight collected could be generalized and could thus be used to drive the design of similar educational experiences. This claim is supported also by the similarities identified with the relevant literature in the field. However, a higher number of respondents to the follow-up questionnaire would have further strengthened the potential use of feedback to improve future offerings of the school. To address this issue, the suggestion is to plan it in due time, which means alerting participants to make the collection of the responses more straightforward.

Acknowledgement

The authors wish to acknowledge the IDEA League alliance (https://idealeague.org) for the promotion and support in the organization of the two editions of the summer school on Computational Design for Additive Manufacturing. The authors also wish to acknowledge the participants for their fundamental contribution to the success of the school.

Bibliography

Blessing, & Chakrabarti. (2009). *DRM, a design research methodology*. Springer Dordrecht.

Blösch-Paidosh, A. & Shea, K. (2021). Enhancing Creative Redesign Through Multimodal Design Heuristics for Additive Manufacturing. *Journal of Mechanical Design*, *143*(10). https://doi.org/10.1115/1.4050656

Blösch-Paidosh, A. & Shea, K. (2022). Industrial evaluation of design heuristics for additive manufacturing. *Design Science*, *8*. https://doi.org/10.1017/dsj.2022.8

Borgianni, Y., Pradel, P., Berni, A., Obi, M. & Bibb, R. (2022). An investigation into the current state of education in Design for Additive Manufacturing. *Journal of Engineering Design*, *33*(7), 461-490. https://doi.org/10.1080/09544828.2022.2102893

Diegel, O., Nordin, A. & Motte, D. (2019). Teaching design for additive manufacturing through problem-based learning. In *Additive manufacturing–developments in training and education* (pp. 139-149). Springer.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D. & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of engineering education*, *94*(1), 103-120.

Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., Wang, C. C. L., Shin, Y. C., Zhang, S. & Zavattieri, P. D. (2015). The status, challenges, and future of additive manufacturing in engineering. *Computer-Aided Design*, *69*, 65-89. https://doi.org/10.1016/j.cad.2015.04.001

Greer, J. R. & Deshpande, V. S. (2019). Three-dimensional architected materials and structures: Design, fabrication, and mechanical behavior. *MRS Bulletin*, *44*(10), 750-757. https://doi.org/10.1557/mrs.2019.232

Leung, Y.-S., Kwok, T.-H., Li, X., Yang, Y., Wang, C. C. L. & Chen, Y. (2019). Challenges and Status on Design and Computation for Emerging Additive Manufacturing Technologies. *Journal of Computing and Information Science in Engineering*, *19*(2). https://doi.org/10.1115/1.4041913

Liu, J., Gaynor, A. T., Chen, S., Kang, Z., Suresh, K., Takezawa, A., Li, L., Kato, J., Tang, J., Wang, C. C. L., Cheng, L., Liang, X. & To, A. C. (2018). Current and future trends in topology optimization for additive manufacturing. *Structural and Multidisciplinary Optimization*, *57*(6), 2457-2483. https://doi.org/10.1007/s00158-018-1994-3

Montemayor, L., Chernow, V. & Greer, J. R. (2015). Materials by design: Using architecture in material design to reach new property spaces. *MRS Bulletin*, *40*(12), 1122-1129. https://doi.org/10.1557/mrs.2015.263

Prabhu, R., Miller, S. R., Simpson, T. W. & Meisel, N. A. (2020). Exploring the Effects of Additive Manufacturing Education on Students' Engineering Design Process and its Outcomes. *Journal of Mechanical Design*, *142*(4). https://doi.org/10.1115/1.4044324

Rosen, D. W. (2014). Research supporting principles for design for additive manufacturing. *Virtual and Physical Prototyping*, *9*(4), 225-232. https://doi.org/10.1080/17452759.2014.951530

Rosen, D. W. (2016). A review of synthesis methods for additive manufacturing. *Virtual and Physical Prototyping*, *11*(4), 305-317. https://doi.org/10.1080/17452759.2016.1240208

Sawyer, R. K. (2005). *The Cambridge handbook of the learning sciences*. Cambridge University Press.

Schauer, A. M. K., Fillingim, K. B., Pavleszek, A., Chen, M. & Fu, K. (2022). Comparing the effect of virtual and in-person instruction on students' performance in a design for additive manufacturing learning activity. *Res Eng Des*, *33*(4), 385-394. https://doi.org/10.1007/s00163-022-00399-8

Tashakkori, A., Teddlie, C. & Teddlie, C. B. (1998). *Mixed methodology: Combining qualitative and quantitative approaches* (Vol. 46). sage.

Thomas-Seale, L. E. J., Kanagalingam, S., Kirkman-Brown, J. C., Attallah, M. M., Espino, D. M. & Shepherd, D. E. T. (2022). Teaching design for additive manufacturing: efficacy of and engagement with lecture and laboratory approaches. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-022-09741-6

Thompson, M. K., Moroni, G., Vaneker, T., Fadel, G., Campbell, R. I., Gibson, I., Bernard, A., Schulz, J., Graf, P., Ahuja, B. & Martina, F. (2016). Design for Additive Manufacturing: Trends, opportunities, considerations, and constraints. *CIRP Annals*, *65*(2), 737-760. https://doi.org/10.1016/j.cirp.2016.05.004

Williams, C. B. & Seepersad, C. C. (2012). *Design for additive manufacturing curriculum: A problem-and project-based approach* In 2012 International Solid Freeform Fabrication Symposium, University of Texas at Austin.

Williams, C. B., Sturm, L. & Wicks, A. E. (2015). Advancing Student Learning of Design for Additive Manufacturing Principles Through an Extracurricular Vehicle Design Competition. ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Appendix

The Follow-Up Questionnaire

The follow-up questionnaire comprises 15 questions in total, and contains three different question types, namely a single- and multiple-choice questions, and open-ended questions. Questions 1-4 target general characteristics of the respondents to help interpret their answers in the reminder of the questionnaire in the context of their demographics. The motivation of a respondent to participate in the summer school as well as the relevance of the summer school for their future studies/ career are addressed in Questions 5-11. Investigation on the usefulness and purpose of the design challenge “Shapeways” prize for the summer school are addressed in Questions 12-13. The two questions target the respondents that received the award. Finally, Questions 14-15 compare the summer school to similar courses in which the respondents were involved during their studies:

1. Are you currently a master's student, a PhD candidate, a researcher/Postdoc or a professional? (*A single-choice question*)
    - Master
    - PhD candidate
    - Researcher/Postdoc
    - Professional
    - Other (*allowing the respondent to fill in a specific answer*)
2. If you are a professional for which industrial sector are you currently working? (*A single-choice question*)
    - Aerospace & Defense
    - Healthcare
    - Consumer goods
    - Transportation
    - Energy & Materials
    - Chemicals
    - Transportation & Mobility
    - Industrial Equipment
    - Consulting
    - Other (*allowing the respondent to fill in a specific answer*)
3. If you are a master's student, a PhD candidate or a researcher/postdoc, what is your current field of study or research? (*Open-ended question*)
    - *The respondent is asked to provide a written answer*
4. Which edition of the summer school did you attend? (*A single-choice question*)
    - 2020
    - 2021
5. What motivations have pushed you to apply to the Computational Design for Additive Manufacturing summer school? (*A single-choice question*)

- I have a passion for Additive Manufacturing technologies. It is my field of study or research.
- I was not an expert on Additive Manufacturing, and I wanted to know more.
- Other (*allowing the respondent to fill in a specific answer*)

6. After more than 1 year from the end of the summer school, do you believe that the topics learned during the summer school have been relevant for the projects/activities you are currently involved in? (*A single-choice question*)
   - Yes
   - Yes, but not for the current projects/activities I am currently involved in
   - No
7. If yes, could you explain for which purpose (e.g., for your thesis project, for your daily work in the company)? (*Open-ended question*)
   - *The respondent is asked to provide a written answer*
8. After more than 1 year from the end of summer school, do you believe that the topics learned during the summer school could be relevant for your career in the long term? (*A single-choice question*)
   - Yes
   - No
   - I am not sure (*allowing the respondent to fill in a specific answer*)
9. If yes, could you explain for which purpose (e.g., for career advancement, for future projects)? (*Open-ended question*)
   - *The respondent is asked to provide a written answer*
10. Considering the "Computational Design for Additive Manufacturing" subject of the summer school, are there any topics or activities that were not discussed/performed or were discussed/performed only marginally that, instead, you consider relevant? (*Open-ended question*)
    - *The respondent is asked to provide a written answer*
11. To what extend the following topics have influenced your career or your studies the most? (*Rate topics from 1 to 5 to denote lowest and highest relevance, respectively; one topic at the least, and all five topics at the most; a multiple-choice question*)

Topic \ **Relevance**	1	2	3	4	5
Multi-material printing					
Cellular/lattice structures					
Topology optimization/ generative design					
Design possibilities unlocked by Additive Manufacturing technologies					

The design challenge					

12. If you have received the Shapeways prize for the design challenge, did you find it useful and have you had the chance to use it? (*A single-choice question*)
    - Yes, I have used it
    - No, I have not used it
    - I won the prize, but never received it
    - I did not win the prize
    - Other (*in this special case the respondent can provide an elaborate written answer*)
13. If you have used it, could you please share with us for what you used it for (e.g., personal use, professional/research use) and for which product category? (*Open-ended question*)
    - *The respondent is asked to provide a written answer*
14. Compared to the other online learning experiences you have had the chance to attend or be engaged in (e.g., university courses, other summer schools), did you find the Computational Design for Additive Manufacturing properly engaging? (*A single-choice question*)
    - Yes, one of the most engaging learning experiences I have lived
    - It has been as engaging as the other learning experiences I have lived
    - I felt unengaged by the online modality and how the summer school was structured.
    - Other (*allowing the respondent to fill in a specific answer*)
15. Could you briefly explain why you felt engaged or not engaged (see Question 14) during the summer school? (*Open-ended question*)
    - *The respondent is asked to provide a written answer*

Supplementary Questionnaires

The structure for the two supplementary surveys on the teaching experiences, and students' feedback performed right after each summer school edition by the IDEA League.

1. Are you a master student or a PhD candidate? (*A single-choice question*)
2. Were you satisfied with the overall level of this summer school? (*A single-choice question, 1 to 5 scale*)
3. Were you satisfied with the way the programme was structured during the week? (*A single-choice question, 1 to 5 scale*)
4. Were you satisfied with the lecture of Lecturer No.# (*A single-choice question, 1 to 5 scale*)
    - This question is repeated for every lecturer involved with the course.
5. To what extent did you find the lectures inspiring? (*A single-choice question, 1 to 5 scale*)
6. Were you satisfied with the contribution of the practitioners/supervisors? (*A single-choice question, 1 to 5 scale*)
7. To what extent do you believe that the summer school has effectively tackled the topic of Computational Design for Additive Manufacturing? (*A single-choice question, 1 to 5 scale*)

8. Were you satisfied with the overall organization of the programme? (*A single-choice question, 1 to 5 scale*)
9. Were you satisfied with the online set-up of the programme specifically? (*A single-choice question, 1 to 5 scale*)
10. Were you satisfied with the level of information you received prior to the start of the programme? (*A single-choice question, 1 to 5 scale*)
11. Did you have time to build a network with fellow students? (*A single-choice question*)
    - Yes
    - No
    - Other (*allowing the respondent to fill in a specific answer*)
12. Were you satisfied with balance between the lectures and practices (including the design challenge)? (*A single-choice question*)
    - Yes
    - No
    - Other (*allowing the respondent to fill in a specific answer*)
13. Do you have any comments/suggestions concerning the design challenge? (*An open-ended question*)
14. Were you satisfied with the set-up of the design challenge? (*A single-choice question, 1 to 5 scale*)
15. How did you work for the design challenge? (*A single-choice question, 1 to 5 scale, 1 - Always with my group and 5 - Always individually*)
16. Would you recommend that other fellow students to take part in a such programme? (*A single-choice question*)
    - Yes
    - No
    - Other (*allowing the respondent to fill in a specific answer*)
17. What did you enjoy most about the programme? (*An open-ended question*)
18. Do you have any suggestions or comments for improvement of the programme? (*An open-ended question*)

Teaching supercomputing and software engineering skills to science and engineering students

Ludovic Räss

Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Zurich, Switzerland
Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland

Mauro A. Werder

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland
Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Zurich, Switzerland

Ivan Utkin

Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Zurich, Switzerland
Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland

Samuel Omlin

Swiss National Supercomputing Centre CSCS, Lugano, Switzerland

Abstract

We describe a newly created Master-level course about numerically solving partial differential equations (PDEs) on graphical processing units (GPUs), both on local machines, on high-performance computing (HPC) clusters and supercomputers. The course is aimed at *domain-science* students, which we broadly define as non-computer science students, such as earth-science, physics, engineering, etc. students. Besides the core content, the course aims also at teaching other essential skills needed for the domain scientist to successfully conduct numerical research, including software engineering skills (e.g., git and GitHub, testing, documentation), tools (e.g., VSCode and remote HPC access), teamwork and project management. The course is research-based as it closely follows the workflows, we use in our daily research activity. The course teaches its content through a hands-on, project-based approach with weekly assignments and two large projects as a core part of the course. We show that student grades and satisfaction is excellent, however, the high workload of the teachers warrants refinements in future iterations of the course.

Introduction

High-performance computing (HPC) takes an increasingly bigger role in modern science, utilising computers ranging between small local clusters to supercomputers. We, earth and fluid mechanics scientists, and many other domain scientists (in contrast to computer scientists) nowadays write code and run it on HPC-clusters. HPC changes over time, with the current standard moving towards using hardware accelerators such as graphics processing units (GPUs). But also on a smaller scale, workstations with one or several GPUs deliver compute capabilities similar to what entire research clusters would have less than a decade ago. Rapidly changing hardware also puts high requirements on scientific software development in order to leverage the constantly new capabilities efficiently (Dongarra, 2022).

As an example, scientific computing in earth sciences, which is the domain of the authors, leverages the continuous increase in the amount of observational data and available computing capabilities (Morra et al., 2021). This allows, for instance, to resolve all (or at least more) relevant physical processes from first principles instead of parameterising them and, thus, allows to test hypotheses on dynamical processes.

Advances in programming languages and scientific software packages make it possible for the domain scientist to now design and code HPC simulations without years of training. New languages such as Julia[1] (Bezanson et al., 2018) were designed to address the two-language barrier: namely allowing for a single codebase to serve both during prototyping and during production simulations. Previously, prototyping was typically done in a high-level but slow language, which then needed to be translated into a fast but low-level language for the production simulations. Skipping this step reduces a costly development cycle avoiding code duplication and errors when switching between higher-level prototyping codes and lower-level HPC production codes (Churavy et al., 2022). Coincidentally, these developments now also make it possible to teach students how to produce performant HPC-GPU applications within a just one semester long course.

We found that there was a gap, which we could fill, in ETH Zurich's (ETHZ) curriculum with respect to GPU based HPC with a focus on physics-based simulations. Thus, we designed and now twice taught a course which aims to spread the basics of HPC and supercomputing on GPUs to the (future) domain scientist, i.e., to science and engineering students. The course covers iterative algorithms for solving partial differential equations (PDEs) efficiently on GPUs (Räss et al., 2022), their implementation, performance considerations, without relying on external libraries as much as possible (with exception of visualisation and lower-level building blocks such as hardware specific software layers).

This manuscript is structured as follows: we first describe how we set up the course with focus both on a conceptual viewpoint as well as on technical aspects. We then discuss the outcomes of the course in terms of student participation, feedback, grades and handed in assignments and projects. The aim of this paper is to reflect on how our research-, project-, and tooling-based course achieves conveying the full skill set needed for our students to get started with computational domain science.

Course organisation and setup

To achieve our goal to introduce students to coding HPC simulations, we do not only teach them how to write numerical code but also project management skills and how to use software-engineering tooling, in the spirit of Software Carpentry (Wilson, 2006) and beyond (Smith, 2018). These computational competencies complement other skills our course emphasises on such as the use of supercomputing for domain science applications and the elaboration of a research process. We feel that all of these skills are equally important for a student to be successful as a computational domain scientist.

We pursue a research-oriented learning approach in the course. Healey (2005) writes "[…] students are likely to gain most benefit from research when they are actively involved in carrying out research projects, whether in part or in whole.". Healey (2005) furthermore decomposes the research-teaching nexus along three dimensions: (1) emphasis on research content versus research process, (2) students as audience or participants, and (3) teacher-focused or student-focused teaching. As stated in the above quote, one of the ways to produce a research-oriented teaching style is through projects. For instance, Pinho-Lopes and Macedo (2016) found that project-based learning models are well received by students. This approach

[1] http://www.julialang.org

is a form of active learning where the students develop the knowledge themselves rather than it being presented by the teachers (Prince & Felder, 2006).

A particular focus of our course is that we want to achieve that students feel *ownership* of the code they produced, the tools they learned and the projects they made during the course. To achieve this, we designed our course to be delivered in a *hands-on* manner. Besides the obvious, namely that the students need to write code for the course, hands-on also means to us that they need to learn and apply the skills and tools needed to successfully create scientific models and run simulations with them: software-engineering tools (e.g., version-control with git, GitHub, editors/IDEs, testing) and project management skills (e.g., writing documentation and reports, running simulations). We convey these skills via a project-based teaching approach.

Course structure

The course consists of 14 weekly lectures of 3h each spanning one semester. The course includes concise lecturing, weekly assignments, a project common among all students, and a personal final project. We use lectures as a basic course unit; typically, each lecture and its associated assignment cover one topic. Table 1 gives an overview of the covered material.

Lectures	Material taught		Exercises	
	main-topics	side-topics	main-topics	side-topics
Why Julia and GPUs	PDEs, GPUs	Tools for the job (Julia, Jupyter notebook)	Numerical solutions, predictive modelling	Visualisation
PDEs and physical processes	Solving PDEs	Git and version control	Solve basic physics (advection, diffusion, reaction)	Install Julia, create git repository
Solving elliptic PDEs	Fast iterative elliptic PDE solvers	Julia REPL and package manager	Implicit iterative solvers in 1D and 2D	Parametric study
Porous convection	A physical model for thermal porous convection	Julia's project environment	Thermal porous convection in 2D	2D visualisation
Parallel computing	Performance considerations, shared memory parallelisation	Unit testing in Julia	Performance evaluation	Unit testing
GPU computing	GPU architecture, array and kernel programming	Reference testing in Julia	Data transfers and optimisations, solving PDEs on GPUs	Unit and reference tests
xPU computing	The two-language barrier, backend portability	Continuous integration (CI) and GitHub Actions	3D thermal porous convection	Continuous integration and GitHub runners
MPI and distributed computing	Distributed memory computing, MPI	Getting started on a supercomputer	Distributed computing on GPUs	Running on a supercomputer
Advanced optimisations	Scientific applications' performance		Shared memory and registers manual tuning	
Projects	Solving PDEs on GPUs	Documentation, GitHub repository, continuous integration		

Table 1: Material and topics discussed during the course listed as main- or side-topics.

New material is introduced during the first 10 lectures, the remaining 4 lectures are reserved for the final project. The first two lectures provide the students the opportunity to familiarise themselves with the Julia language, differential equations and allow them to set up the tooling required for the class. To assure a smooth start, the coding related to the two first lectures happen in Jupyter notebooks hosted on a JupyterHub server (Granger & Pérez, 2021). Having a ready-to-use environment allows to quick-start the course avoiding the need to get per-person environment configurations. At lecture 3, we require everyone to have their personal Julia installation. Lectures 7-9 serve as a basis for the first, common project. Finally, during lectures 11-14 of the course, students work on a personal final project of their choice. They can choose among implementing domain specific PDEs they want to solve or applying performance optimisations to the codes from their first project, using the tooling and skills acquired during the course.

Each lecture contains a concise lecturing part used to introduce the basic concepts to be addressed. The new concepts are programmatically exemplified during the class by means of live-coding and small in-class exercises. Important concepts are practised using active learning sequences. The general approach is to provide an incremental build-up of knowledge and competencies throughout the course and provide to the student a set of skills they can further apply in the two projects (Table 1).

In summary, the course is founded on project-, tooling- and research-based teaching to convey the students the basis of HPC on GPUs.

Technical aspects

To provide a smooth learning experience to students we rely on a custom technical stack composed of specific hardware infrastructure, open-source software solutions and ETHZ-provided learning and communication platforms. This technical stack forms the backbone of our course and thus warrants a description. However, readers less interested in this aspect of the course should skip to the last paragraph of this section.

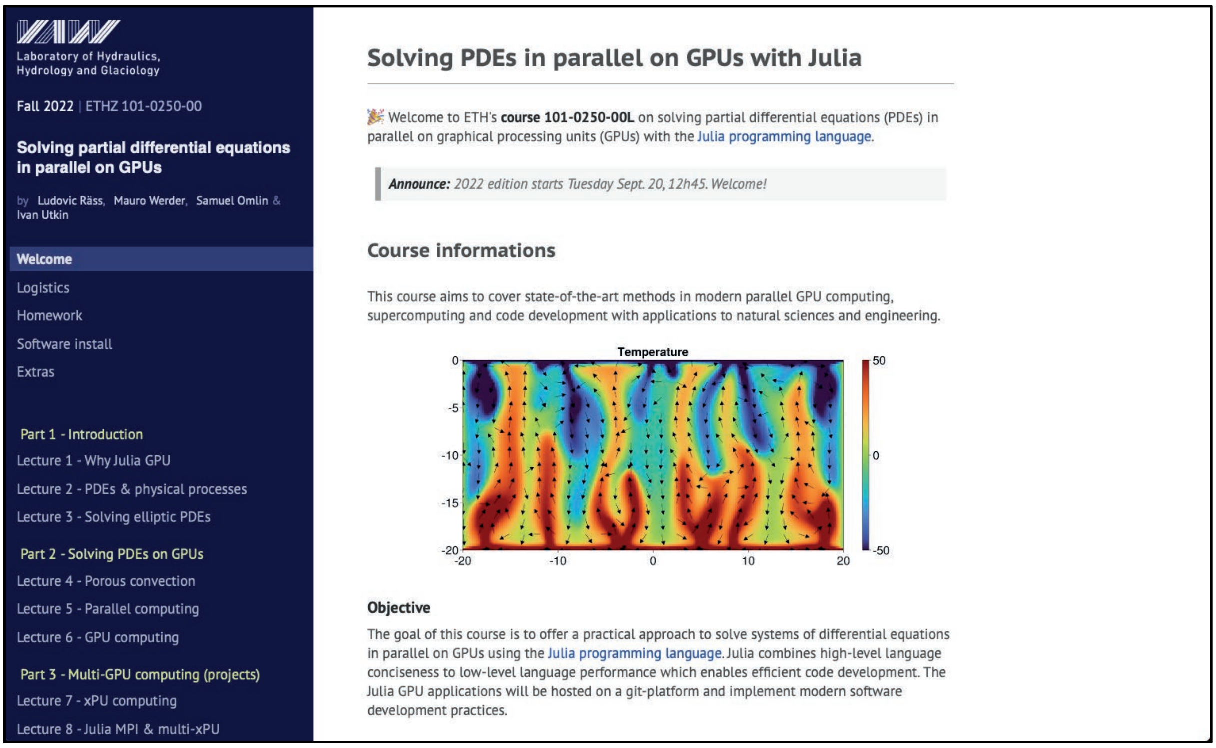

Figure 1: Screenshot of the 2022 edition course website https://pde-on-gpu.vaw.ethz.ch/ landing page.

The core of the course's technical stack is a GitHub (a code-hosting website) repository[2] including the course's website deployed using GitHub-pages at the custom ETHZ-provided address https://pde-on-gpu.vaw.ethz.ch/ (Fig. 1). We rely on a fully Julia-based stack combining literate programming[3], which is a programming technique combining text/documentation with the code (Knuth, 1984), and a static website generator[4] to generate the Jupyter notebooks, demo scripts and to deploy the content online; all is generated from a single master script. The notebook can further be turned into slides which can be presented with Jupyter using the RISE[5] plugin. The single-script approach avoids code and content duplicates which would lead to tedious maintenance and version tracking overhead. We automated most of the workflow by creating helper scripts that would trigger the deploy pipeline. During literate-code processing, we added the capability to parse for specific keywords which allows us to deploy assignments with hints or solutions depending on the needs, thus allowing us to keep the assignment and its solution in one master script.

We rely on a set of digital support applications, namely GitHub, Moodle (online learning platform), Zoom (video conferencing) and Matrix/Element[6] to enable the best experience and support a hybrid (in-person / remote) course format. Besides deploying the course website, we also use GitHub as a platform to handle students' weekly assignments and final projects. Hand-ins need to be pushed to GitHub prior to the deadline and a git commit hash is further uploaded to Moodle, a bot then downloads the student's code automatically to ETHZ servers. We rely on Moodle for ETHZ-only secure access such as sharing sensible information, collecting git commit hashes as well as its integrated JupyterHub. We use Zoom to broadcast and record all lectures and provide recordings on Moodle to allow students with conflicting schedules to still follow the course. We use Matrix/Element –an open standard for interoperable, decentralised, real-time communication– for instant messaging among course participants. The service, staff-chat and student-chat by ETHZ can be accessed via the cross-platform Element client. The class-related chat allows teachers to share general information with students via a "General" info channel and to run Q&As in a separate "Helpdesk" channel. The benefit of the approach avoids repetition of help as the Q&A is accessible to everyone enrolled in the class. Also, it pushes students to ask precise questions and we encourage the approach of using a minimal (not) working example in their posts that would precisely specify their issue. We also motivate students to take over the Q&A whenever possible such that they could provide help among each other and learn from it. The service being opt-in, everyone is free to filter the info to their needs.

To ensure a smooth start, we value that students can access a ready to go coding and learning environment. This step is important as getting the computing environment to be ready on the students' laptops may be very time consuming and would not provide a very motivating introduction for the course. Thus, for this step, we rely on JupyterHub. In the first edition of the course, we manually deployed a stripped-down version of JupyterHub[7] on one of our servers which the students could then access. Starting from the second edition of the course we used a JupyterHub instance which is now available from ETHZ with Moodle integration.

Among the goals of the course is the development of multi-GPU applications. Large-scale GPU resources are not so common, but the Swiss National Supercomputing Centre (CSCS) supported our course with 4'000 node hours compute time on the Piz Daint GPU supercomputer[8] in 2022. In 2021, we used the GPU computing resources offered by the Swiss Geocomputing Centre (Unil) where students could get free compute time on the Octopus

[2] https://github.com/eth-vaw-glaciology/course-101-0250-00
[3] https://github.com/fredrikekre/Literate.jl
[4] https://github.com/tlienart/Franklin.jl
[5] https://rise.readthedocs.io/en/stable/index.html
[6] https://matrix.org/
[7] https://tljh.jupyter.org/en/latest/
[8] https://www.cscs.ch/computers/piz-daint/

supercomputer. We could use the JupyterHub instance provided by the CSCS to get students smoothly started on Piz Daint including its GPUs, before transitioning to a more classical development and script-submission workflow on the supercomputer.

JupyterHub and notebooks provide a good quick-start environment but rapidly hit limitations in the way we do numerical modelling. Also, they cannot currently be used to efficiently launch processes in parallel and may lead to significant performance overhead. For this reason, we then transition to running Julia and simulations "locally", on students' laptops and on Piz Daint for the first and second parts of the course, respectively. This is seamlessly achieved thanks to Visual Studio Code (VSCode, a code editor)[9] and its Julia extension[10]. VSCode also features a Remote-SSH[11] extension which greatly simplifies the access to remote compute resources such as the Piz Daint supercomputer at CSCS. Using VSCode permitted all the students to have a ready to use local or remote Julia installation and we had not a single issue with students setting this up between two lectures over the course of a week (no support was needed from the teaching staff).

The Julia language consists of a standard library to which specific functionalities such as visualisation, maths-operations, parallelisation, or backend specific computations, can be added by using packages. We specifically use packages related to GPU computing and contribute to part of these. GPU-related packages such as CUDA.jl (Besard, Churavy, et al., 2019; Besard, Foket, et al., 2019) or AMDGPU.jl are grouped in the JuliaGPU[12] organisation. The building-blocks packages we further use in the course and contribute to are ParallelStencil.jl[13] (Omlin & Räss, 2022) and ImplicitGlobalGrid.jl[14] (Omlin et al., 2022).

In summary, the interactive course material is deployed to the course website directly from source-code scripts using an automated pipeline. The coding in class is started on Julia notebooks that are running on JupyterHub instances on ETHZ servers (CPU only) and on Piz Daint at CSCS (multi-GPU), this allows the students to hit the ground running and to not get bogged down with installation technicalities at the onset. In a second step, students transition to a local Julia installation on their laptops and run parallel Julia GPU scripts on Piz Daint outside of the notebook environment.

Evaluating student performance

We evaluate student performance in a composite way including weekly exercises, a common project, and a personal final project, contributing 30%, 35% and 35% to the final grade, respectively. Note that no examination is held.

During the first 6 lectures, students need to hand-in 5 out of 6 assignments which we use to give them prompt feedback and evaluate as well (Table 1). The main reason being to keep students motivated in the first weeks such that they can better appreciate the following steps. The project-work during lectures 7-9 is on the same project for the entire class which aims at bringing together the skills learned thus far, namely resolving multi-physics flow processes in 3D on multiple GPUs using the Julia language, in one self-contained unit. This first project also provides a consistent way to grade all students based on the same tasks presented to them with clear steps. The final project permits students to apply the skills they acquired during the course to their domain science, such as earth-sciences, engineering, or physics (see Table 1 for a summary of the course design).

[9] https://code.visualstudio.com/
[10] https://www.julia-vscode.org/
[11] https://code.visualstudio.com/docs/remote/ssh
[12] https://juliagpu.org/
[13] https://github.com/omlins/ParallelStencil.jl
[14] https://github.com/eth-cscs/ImplicitGlobalGrid.jl

The projects provide an ideal way to assess students' autonomy and ability to integrate the concepts learned from class with a clearly defined objective, namely, to write a Julia code that solves porous thermal convection in 3 dimensions (3D) and runs on 64 GPUs on the Piz Daint supercomputer at CSCS. Besides writing their own code and running it, students had to document their code using docstrings and code annotations, create unit and reference tests for their software, run the tests with continuous integration (CI) using GitHub Actions[15] and provide a report in the form of an enhanced README-file in their repository.

For their personal final projects, students would ideally try to identify differential equations relevant to their scientific interests and try to solve them using the newly learned methods. The evaluation of this final part is more challenging to ensure fairness between the different projects. We decided to value some formal items such as content and quality of the final report (an online README-file or automatic generated documentation) and give additional points for creativity and relevance. Project-based evaluations are interesting as they train students to manage their timing, allow them to organise their work with some freedom but also pushes them to report about their work in a concise way.

Teaching and learning in this course

Here we summarise our experiences from teaching two editions of the course and how we perceive the students were learning the material. The management of the course always went smoothly, although the workload is high, both for students and teaching staff. The course is very participative which demands extra resources on both students and teachers' side. We decided to limit the maximum number of participants to the course to 20 and 25 students in the first and second course edition, respectively, to ensure good quality and have enough bandwidth for supporting them. This choice paid off as we could provide that required support. We were also positively surprised that the broad variety in students' background (earth sciences, civil engineering, computer sciences, computational sciences and engineering, electrical engineering, mechanical engineering and robotics, mathematics, physics) did not hinder the teaching but rather provided material for constructive exchanges among students. According to the very positive student evaluations we got for these first two editions (Fig. 4), we can report that students enjoyed the practical approach towards demystifying GPU supercomputing. Students put in hard work and were enthusiastic about the course.

Assignments in the first 6 lectures of the course are important. They significantly help students to learn the material, both the core content as well as the additional skills and tools and push them to do the exercises during the course; this view is also shared by the students (Fig. 4d). They also provide a way for students to get feedback on their work assuming the teaching staff has enough time to promptly correct the hands-in and provide that feedback. The assignment correction is consuming about 8 to 10 hours of the teaching staff's resources on a weekly basis. For the second edition of the course, we hired a teaching assistant which significantly improved the early feedback we could give to the students about their exercises.

The final projects provided the students the opportunity to apply their GPU and HPC knowledge to solve a problem of interest in their scientific field. The projects required them to apply all the skills and tools learned in a integrated fashion. Most of the projects partly combined suggested topics with some variations to make them fit to the students' interests. Among the successful projects, we selected two projects from each year of the course to showcase here: In the first edition of the course, one student team tackled a 2D Navier-Stokes flow problem relying on a geometric multigrid solver running on Nvidia GPUs (Fig. 2a). Another student resolved shear heating activated shear-band formation due to thermomechanical coupling in 2D on GPUs (Fig. 2b). From the second edition of the course, we selected one project resolving acoustic

[15] https://docs.github.com/en/actions

wave propagation in 3D on multi-GPUs with an efficient convolutional perfectly matched layer (CPML) boundary condition implementation. This code will serve as the basis to perform full waveform inversions (Fig. 2c). The other highlight project from the second course edition resolves flow migration in viscously deforming porous media exhibiting the occurrence of solitary waves of porosity (Fig. 2d).

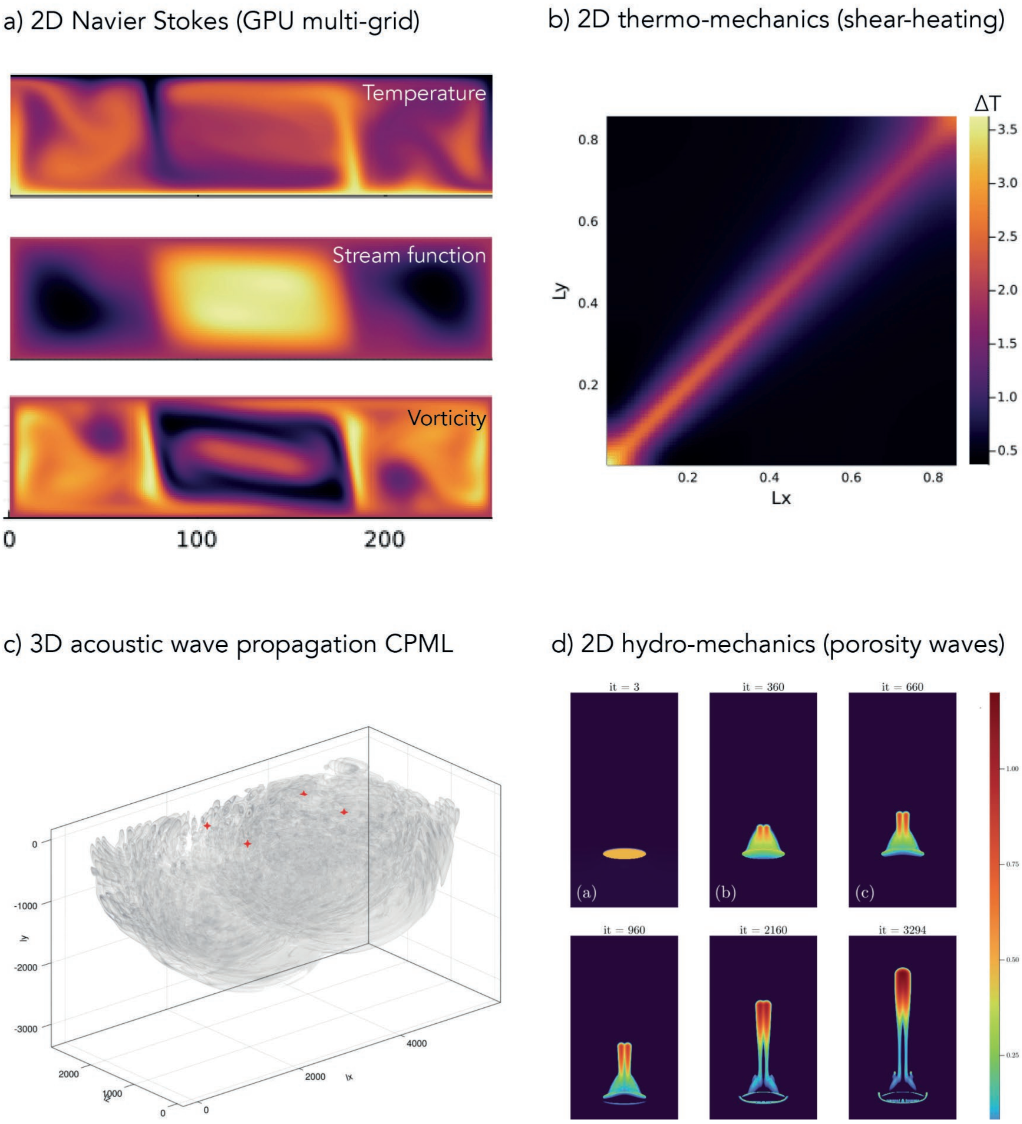

Figure 2: Selected student projects gallery. a) 2D Navier-Stokes simulation of convecting fluid on GPUs using a multi-grid solver[16]; b) 2D thermo-mechanical coupling leading to the formation of a ductile shear zone owing to shear-heating[17]; c) 3D multi-GPU acoustic wave propagation with a convolutional perfectly matched layer (CPML) boundary condition by Giacomo Aloisi[18]; and d) 2D hydro-mechanical coupling leading to the formation of solitary waves of porosity in deformable porous media by You Wu[19].

16 https://github.com/ntselepidis/FinalProjectRepo.jl/blob/main/docs/part2.md
17 https://github.com/YWang-east/course-101-0250-00-FinalProject/blob/main/docs/part2.md
18 https://github.com/GiackAloZ/AcousticWaveCPML.jl
19 https://github.com/youwuyou/HydroMech.jl

Throughout the course we ensure that the student exercises and projects also include and foster the additional skills we aim to teach (see Table 1 "side-topics"). The software engineering skills are directly tested as they are part of the exercises and projects: code hosting and exercise submission is using GitHub and git; the students are required to submit unit and reference tests; documentation is in form of readme documents; and running code on the HPC clusters is done using direct integration on the code-editor they are using. The students generally work in teams of two for the project work and thus practise teamwork skills; however, a direct assessment of these skills is not easy and not done within the course. Project management skills, such as report and documentation writing, keeping track and organising simulation outputs, are needed and integral work for both projects. Taken together with the actual numerical computing, these activities mean that student do practise all those additional skills and that they really have ownership of their final project as they produced everything in that project in a setting which could be used in a research environment.

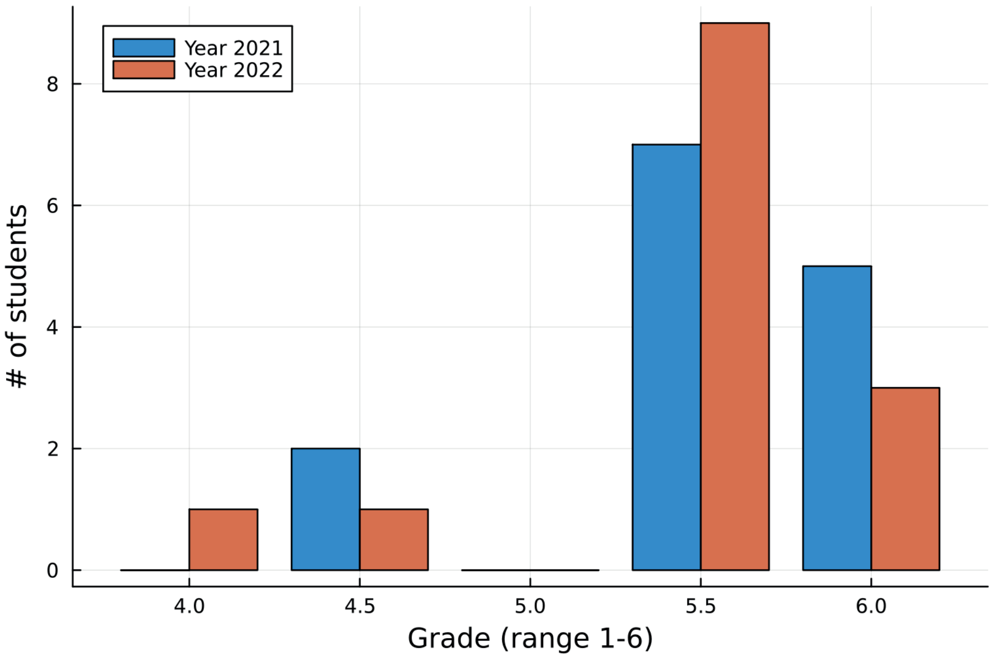

Figure 3: Student grades distribution for the two first editions of the course.

To gauge the student's perception of and happiness with the course, we rely on the standardised end-of-course survey of ETHZ and on informal feedback. Figure 4 shows a few selected answers from this survey, with the full survey available in the supplementary material. In general, the survey shows very positive evaluations from the students (Fig. 4a). Points of contentions are mostly related to workload and credit points (Fig. 4b), however, there is no clear signal there. The big effort on our side with preparation of material presented on the course website and the assignments are appreciated (Fig. 4c,d). Particularly good, we feel, is the positive feedback on the question whether the students could explain the material to a younger student (Fig. 4e). Also, informal feedback was good, with statements such as “not many courses like this are available to master students, so kudos to you!”. We also perceive that the students learn a lot in this course, as is exemplified by some outstanding final project (Fig. 3) and that they are well motivated as exemplified by the close interaction with them.

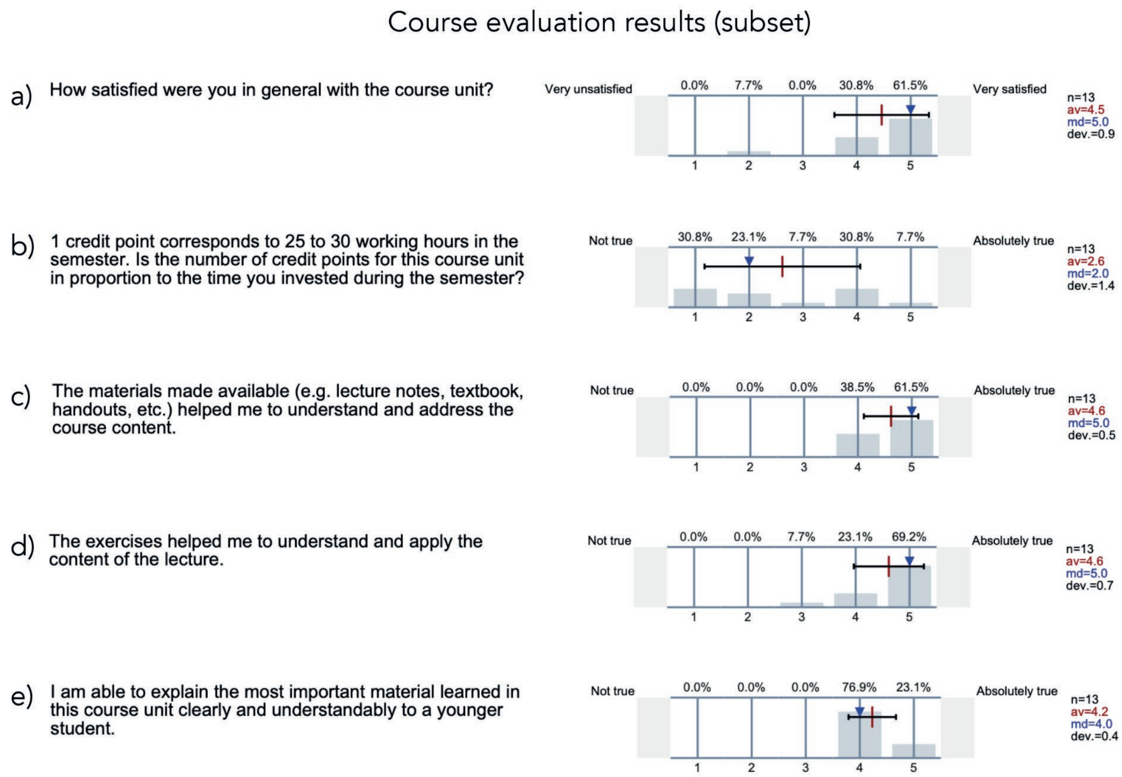

Figure 4: Course evaluation results for the 2022 edition. a) General satisfaction; b) Credit points versus workload satisfaction; c) Usefulness of support material; d) Exercises as knowledge transfer; and e) Ability to transfer acquired knowledge.

Student performance

The good grades reflect the students' involvement in the lecture (Fig. 3): all passed with more than five out of six receiving excellent grades. On average over the two first editions, we experienced about 20-25 inscriptions and 5 to 6 dropouts. These dropouts were related to too much workload in the whole of the students' curriculum and thus their need to reduce the number of courses.

Discussion

Teaching this course is a rewarding experience due to the combination of being able to teach subjects of high interest, namely GPU computing as well as software engineering tools, and due to the close interaction with highly motivated students. Thinking back to our days as students, this certainly would have been a course which we would have enjoyed taking and it would have helped jumpstart the scientific career we are now pursuing. The downside of the course is that it requires a high teacher workload, which needs to be reduced to keep this course sustainable in the long run.

The course is surprisingly well aligned to ETHZ's teaching strategy which states that "Research and teaching must be closely linked" and that "the acquisition of soft skills, […,] computational competencies, and the ability to analyse complex issues" (p.36) are key skills to be taught (Cantalou et al., 2021). The former being fulfilled as we are teaching the methodology, we employ during our research work (Healey, 2005). One of our intentions to teach this course is to prepare current and future Master and PhD students to work with us. Indeed, one current Master student completed the course as preparation for their thesis with us, and for one freshly started PhD student the upcoming course in 2023 will be an integral part of their doctorate. Besides the research-oriented focus, the course aims at conveying many other skills such as software engineering, working in a team or project management through a project-based approach. Again, our motivation for this approach was that we want to pass on the knowledge and skills needed to succeed as a computational domain-scientist.

The technological advances over the last decade make a course on solving PDEs on GPUs possible. Numerical computing on GPU commenced in the early 2000s and started getting established with the first release of CUDA (the library to perform general purpose computations on Nvidia GPUs) in 2007 (Vuduc & Choi, 2013). However, until recently performing numerical computations on GPUs either required direct coding in low level languages, such as CUDA C, or the usage of GPUs via highly abstracted interfaces in high-level languages which either restricted capabilities, performance, or both. We feel that only the recent advances in the Julia programming language, made a course as ours possible by allowing to teach the low-level details whilst being easy enough to learn to fit into a semester course. Besides the GPU-computing capabilities, Julia provides a modern open-source software environment embracing many of the industry's best practices such as hosting of code in git-repositories (mostly GitHub) automated testing using continuous integration and having documentation (Hanson & Giordano, 2021). Thus, the Julia ecosystem serves as an ideal backdrop to teach those concepts to students.

Our current research uses the Julia language and its GPU package ecosystem and thus the course is directly based on our research and in the framework of Healey (2005), our course is indeed research-based. In his decomposition of the research-teaching nexus (see Introduction), our course focuses on: (1) the research processes rather than the research content, as we mainly teach a method on how to solve PDEs but no not focus on why one would want to solve those equations in the first place; (2) students in our course are definitely participants in many instances as the hands-on exercises and projects take up the largest part of the course; and (3) our teaching is student-focused, again through the many hands-on sequences, however, we do employ classical, teacher-focused lecturing to cover foundational material at a rapid pace.

One of the driving principles behind the design of this course was that we wanted the students to feel and take ownership of the products they created and the tools that they used (Pinho-Lopes & Macedo, 2016). With this we mean that (1) they develop their model from scratch without help of high-level packages or software, that (2) they use the tool we teach them (e.g. git, code editor, unit testing, HPC cluster interaction) self-reliantly and naturally by the end of the course, that (3) they conduct the final project from start to finish employing all their learnt skills and tools, and that (4) they help each other through team work or via help on the group-chat. Note that taking ownership is a process and that we guide the students towards it throughout the course. Indeed, Prince & Felder (2006) state that in problem-based teaching it is important to provide at first a scaffolding for the students which is then gradually removed as they acquire the needed skills. We feel that by the end of the final project they indeed own their work as they created it from the ground up with tools they know how to employ. The research and project-oriented learning approach enabled these developments and confirmed in our case that active learning and involving students in research-like projects was a positive experience (Pinho-Lopes & Macedo, 2016).

There are certainly challenges with this course which need to be addressed to take it into the future. The student-feedback needs to be prompt such that students can profit reliably from the material covered and such that they are ready to absorb new knowledge building on previous lecture content. This involves much manual labour, and the help of the teaching assistant was invaluable in the 2022 edition of the course. Going forward we aim to make assignment correction and feedback preparation less time consuming, for this we will investigate some auto-grading options or self-grading parts of the assignment by the students themselves. One idea is that students code-review amongst each other (another important software engineering skill) and thus provide peer-feedback.

Regarding the class size, of note is that in the 2022 edition of the course, the waiting list was about as large as the number of spaces in the course; thus, expanding the course could be considered. Thinking big, this type of class is, in our opinion, at the forefront of supercomputing courses whilst teaching of supercomputing skills to Master-level students is very limited. We would expect this material to be of interest to a wide cohort of specialised students. Such a course expansion would require an increase of the teaching staff together with streamlining the assignment corrections as outlined above. Irrespective of whether the course size remains small or is scaled up, certainly, the course will keep on evolving including both its content and the used tools as both will be developed further by the research and open-source communities.

Conclusion

We designed a new course at ETH Zurich to teach domain scientists to numerically solve partial differential equations on graphical processing units using a high-performance/supercomputing approach. The course fills a gap in ETH Zurich's curriculum and builds upon recent advances in programming languages and scientific software packages making it now possible to develop such codes without years of training. In addition to numerical code, we also teach project management skills and software-engineering tools. This allows the students to take ownership of all their scientific workflow. We pursue a research-oriented learning approach with the methods mirroring the ones we employ in our research and with end-of-course projects closely following a research workflow. The computational competencies that are taught align well with ETH's teaching strategy and the course is highly rated by students.

Acknowledgement

We would like to thank the Swiss National Supercomputing Centre (CSCS) for donating 4'000 node hours compute time on the Piz Daint supercomputer and the Swiss Geocomputing Centre at the University of Lausanne for granting students compute time on the octopus supercomputer. We appreciate the JupyterHub server and other resources provided by ETHZ. This research has been supported by the Swiss University Conference and the Swiss Council of Federal Institutes of Technology through the Platform for Advanced Scientific Computing (PASC) program and the Swiss National Supercomputing Centre (CSCS project ID c23). This course would not be possible without the excellent Julia programming language and the unparalleled package ecosystem around GPU computing (https://juliagpu.org/). Furthermore, the tools we used for creating the website and assignments are essential to this course (Literate.jl, Franklin.jl and in particular Tibeaut Lienart, IJulia.jl). We also appreciate the other open-source software which makes this course possible such as JupyterHub, VSCode, GNU/Linux, Matrix/Element and many others. We thank our excellent teaching assistant Alexander Mandt of 2022 and all the future teaching assistants of the courses to come. We thank two anonymous reviewers and the editors for their helpful comments which improved this manuscript.

Bibliography

Besard, T., Churavy, V., Edelman, A. & Sutter, B. D. (2019). Rapid software prototyping for heterogeneous and distributed platforms. *Advances in Engineering Software*, *132*, 29–46. https://doi.org/10.1016/j.advengsoft.2019.02.002

Besard, T., Foket, C. & De Sutter, B. (2019). Effective Extensible Programming: Unleashing Julia on GPUs. *IEEE Transactions on Parallel and Distributed Systems*, *30*(4), 827–841. https://doi.org/10.1109/TPDS.2018.2872064

Bezanson, J., Chen, J., Chung, B., Karpinski, S., Shah, V. B., Vitek, J. & Zoubritzky, L. (2018). Julia: Dynamism and performance reconciled by design. *Proceedings of the ACM on Programming Languages*, *2*(OOPSLA), 1–23. https://doi.org/10.1145/3276490

Cantalou, J., Hierold, C., Buchli, A. & Klinger, R. (2021). *Strategy and Development Plan 2021–2024*. https://ethz.ch/content/dam/ethz/main/eth-zurich/portraet/Strategie/ETH_SEP_21-24_EN_Web.pdf

Churavy, V., Godoy, W. F., Bauer, C., Ranocha, H., Schlottke-Lakemper, M., Räss, L., Blaschke, J., Giordano, M., Schnetter, E., Omlin, S., Vetter, J. S. & Edelman, A. (2022). *Bridging HPC Communities through the Julia Programming Language*. https://doi.org/10.48550/ARXIV.2211.02740

Dongarra, J. J. (2022). The evolution of mathematical software. *Communications of the ACM*, *65*(12), 66–72. https://doi.org/10.1145/3554977

Granger, B. E. & Pérez, F. (2021). Jupyter: Thinking and Storytelling With Code and Data. *Computing in Science & Engineering*, *23*(2), 7–14. https://doi.org/10.1109/MCSE.2021.3059263

Hanson, E. P. & Giordano, M. (2021). *Code, docs, and tests: What's in the General registry?* https://julialang.org/blog/2021/08/general-survey/

Healey, M. (2005). Linking Research and Teaching to Benefit Student Learning. *Journal of Geography in Higher Education*, *29*(2), 183–201. https://doi.org/10.1080/03098260500130387

Knuth, D. E. (1984). Literate Programming. *The Computer Journal*, *27*(2), 97–111. https://doi.org/10.1093/comjnl/27.2.97

Morra, G., Bozdag, E., Knepley, M., Räss, L. & Vesselinov, V. (2021). A Tectonic Shift in Analytics and Computing Is Coming. *Eos*, *102*. https://doi.org/10.1029/2021EO159258

Omlin, S. & Räss, L. (2022). *High-performance xPU Stencil Computations in Julia* (arXiv:2211.15634). arXiv. https://doi.org/10.48550/arXiv.2211.15634

Omlin, S., Räss, L. & Utkin, I. (2022). *Distributed Parallelization of xPU Stencil Computations in Julia* (arXiv:2211.15716). arXiv. https://doi.org/10.48550/arXiv.2211.15716

Pinho-Lopes, M. & Macedo, J. (2016). Project-based learning in Geotechnics: Cooperative versus collaborative teamwork. *European Journal of Engineering Education*, *41*(1), 70–90. https://doi.org/10.1080/03043797.2015.1056099

Prince, M. J. & Felder, R. M. (2006). Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. *Journal of Engineering Education*, *95*(2), 123–138. https://doi.org/10.1002/j.2168-9830.2006.tb00884.x

Räss, L., Utkin, I., Duretz, T., Omlin, S. & Podladchikov, Y. Y. (2022). Assessing the robustness and scalability of the accelerated pseudo-transient method. *Geoscientific Model Development*, *15*(14), 5757–5786. https://doi.org/10.5194/gmd-15-5757-2022

Smith, S. (2018). Beyond software carpentry. *Proceedings of the International Workshop on Software Engineering for Science*, 32–39. https://doi.org/10.1145/3194747.3194749

Vuduc, R. & Choi, J. (2013). A Brief History and Introduction to GPGPU. In X. Shi, V. Kindratenko, & C. Yang (Eds.), *Modern Accelerator Technologies for Geographic Information Science* (pp. 9–23). Springer US. https://doi.org/10.1007/978-1-4614-8745-6_2

Wilson, G. (2006). Software Carpentry: Getting Scientists to Write Better Code by Making Them More Productive. *Computing in Science & Engineering*, *8*(6), 66–69. https://doi.org/10.1109/MCSE.2006.122

Actor-based triage training for pharmacy students

Dominik Stämpfli[1]

Institute of Pharmaceutical Sciences, Department of Chemistry and Applied Biosciences, ETH Zurich
Hospital Pharmacy, Kantonsspital Baden AG

Angela Küng Krähenmann[2]

Institute of Pharmaceutical Sciences, Department of Chemistry and Applied Biosciences, ETH Zurich

Irene Vogel Kahmann[3]

Institute of Pharmaceutical Sciences, Department of Chemistry and Applied Biosciences, ETH Zurich
Hospital Pharmacy, Kantonsspital Schaffhausen, Spitäler Schaffhausen

Peter Wiedemeier[4]

Institute of Pharmaceutical Sciences, Department of Chemistry and Applied Biosciences, ETH Zurich
Hospital Pharmacy, Kantonsspital Baden AG

Andreas Gutzeit[5]

Institute of Pharmaceutical Sciences, Department of Chemistry and Applied Biosciences, ETH Zurich
Department of Health Sciences and Medicine, University of Lucerne
Institute for Radiology and Nuclear Medicine, Klinik St. Anna

Abstract

Background and Purpose: Triaging as a service in pharmacies aims to direct clients towards the right care stream and reduce the workload of other care givers. It is also a prerequisite for newly extended pharmacists' dispensing competencies. Triaging requires the application of clinical knowledge for quick decision-making and effective communication skills, which may be practiced in actor-based training. We aimed to evaluate our newly established actor-based trainings on acute respiratory and abdominal symptoms for pre-registration pharmacy students in terms of student feedback and effectiveness.

Educational activity and Setting: The trainings included passive lectures on history taking, clinical examination, and triage, and active learning segments involving case simulation with actors. Actors were recruited from a drama class and received training

[1] dominik.staempfli@pharma.ethz.ch
[2] angela.kueng@pharma.ethz.ch
[3] ivogel@ethz.ch
[4] wipeter@ethz.ch
[5] gutzeita@ethz.ch

to establish their medical knowledge for improvised reactions. The simulations portrayed different personalities of pharmacy clients, which later included actors with little time and understanding for history taking. During the simulations, students had to diagnose the clinical pictures by themselves, applying their newly acquired knowledge. After the simulations, the focus was on mutual feedback between actors, students, and moderators with an emphasis on perspective change and communication. Simulations were held online. Evaluation data was collected with a feedback form and a pre-to-post questionnaire. A one-sided Wilcoxon signed-rank test was used to compare students' pre-to-post changes in self-reported confidence levels.

Findings: Students majorly described the training with the actors to be very realistic (70.0%); they felt comfortable, but still needed to get used to the situation (50.0%); they learned a lot about themselves (50.0%); and the feedback from the actors was found to be helpful (63.3%) and beneficial for learning about their own perceptions of other people (33.3%). The changes in self-reported confidence levels were statistically significant.

Summary: This evaluation showed that actor-based training can foster pharmacy students' confidence in triaging of acute respiratory and abdominal symptoms, even when conducted virtually. Besides effectively promoting decision-making, working with actors additionally allowed to practise different communication styles and to confront students with various personalities of pharmacy clients.

Introduction

Pharmacists find themselves in a changing profession. Shifting away from other specialist competencies such as compounding, the modern community pharmacist is also a provider of pharmaceutical care, "the pharmacist's contribution to the care of individuals in order to optimize medicines use and improve health outcomes." (Allemann et al., 2014) Whilst optimizing medicines use involves services like performing medication reviews (Blenkinsopp A. et al., 2012) or medication reconciliation (Kwan et al., 2013), improving health outcomes does not always involve medicines straight away. Triaging as a service in pharmacies, where medical needs are assessed and prioritised, may direct clients towards the right care stream (Robertson-Steel, 2006) and reduce the workload of other care givers further down the stream (Paudyal et al., 2011). The British "pharmacy-based ailment schemes" have been reported to resolve medical needs in 68-94% of advised clients (Paudyal et al., 2013), whilst triaging in pharmacies overlaps with medical experts in 70-97.6% of the cases when guidelines or protocols are used (Curley et al., 2016). Similarly, a triaging service with decision trees offered by Swiss community pharmacies has been shown to achieve a resolution rate of 87.4% at three-day follow-up (Stämpfli et al., 2021). Since January 2019, Swiss pharmacists may even treat common illnesses with specified medicinal products, effectively broadening their triage outcome options. This change was brought with the updated Therapeutic Products Act and the Therapeutic Products Ordinance, which extended previously established pharmacist dispensing competencies (Federal Office of Public Health FOPH, 2019). A prerequisite for making use of these extended dispensing competencies is proper triaging and documenting of the encounter.

Proper triaging needs clinical knowledge, examination skills, and acquired competency, learned and practiced in safe training environments. Actor-based or human patient simulation (i.e., using mannequins) training accomplishes that by mirroring actual patient care in an environment with no potential harm to patients nor students (Crea, 2011; Vyas et al., 2011). Students may apply their previously established (theoretical) knowledge in situations "where clinical judgment and conflict resolution also are imperative to providing optimal patient care." (Vyas et al., 2011) In simulations, students may be confronted by an urgent patient situation (e.g., acute respiratory distress), exposing them to the stress of quick clinical decision making without risking poor patient outcomes (Crea, 2011). Simulation of hypertensive patients has been shown to improve pharmacy students' assessment of blood pressure and knowledge of pharmacotherapy, as well as generating high levels of student satisfaction and competence (Seybert & Barton, 2007). However, for a pharmacy encounter to be successful and satisfying (e.g., triaged medical needs), communication skills are required as well. But pharmacists are sometimes described to focus on instructions for use and dosing of medicines rather than patient perceptions and preferences (Koster et al., 2015).

With the seminar "Clinical Trainings," the Institute of Pharmaceutical Sciences at the Swiss Federal Institute of Technology Zurich (ETH Zurich) aims to foster competency in clinical decision-making and understanding of pharmaceutical care for real patients before and after hospitalisation. The pre-registration pharmacy students, who are placed in community pharmacies to work alongside registered pharmacists for their last year of studies, get to deepen their clinical thinking (addressing patients, history taking, questioning techniques, triage), get introduced to simple, non-invasive examinations with a special attention to triage and red flags, and get to expand their clinical interpretation of diagnostic and laboratory evaluations. Three half days of a total of six seminar days make use of simulation trainings and simultaneously focus on communication and provider-patient interaction to incorporate elements of other courses on communication into clinical decision-making and triaging. Earlier iterations of these interactive segments still invited actual patients instead of actors, which was changed with the SARS-CoV-2 pandemic. This paper presents the content of the newly established actor-based trainings and their evaluation.

Aims

The evaluation aimed (1) to assess the actor-based trainings with student feedback and (2) to measure the trainings effectiveness on confidence levels for triaging acute symptoms.

Methods

Educational activity

The seminar days started with a 5-hours passive lecture on history taking, clinical examination, triage, and basics of communication psychology (Schulz von Thun, Carl Rogers) held by a chief physician. Patient cases from visceral surgery, pulmonology, cardiology, and neurology were presented. Clinical pictures included acute coronary syndrome, acute pancreatitis, acute cholecystitis, acute sigmoid diverticulitis, acute stroke, chronic obstructive pulmonary disease, and acute allergic asthma.

After the lectures, simulations took place with two male actors, portraying real cases from a Zurich pharmacy. The actors were recruited from a drama class and received around 10 hours of specific training. This training aimed to establish the actors' medical knowledge for improvised reactions and included reading patient information material on the clinical pictures and one-to-one stage rehearsals with the chief physician for acute coronary symptom and acute pancreatitis. A group of four students were selected to overcome any potential shyness of the whole class and start the conversation whilst their peers observed, gradually stepped in, and supported. Students had to diagnose the clinical pictures by themselves, applying their new knowledge on history taking, clinical examination, and triage. The actor-based training focused on communication styles and quick clinical decision-making on supportive care and pharmacotherapy if clients with symptoms of acute coronary symptoms and acute pancreatitis presented themselves in a pharmacy. Using actors also enabled to portray different personalities of pharmacy clients: it was possible to start with grateful and willing clients and then move on to personalities who had little time and understanding for history taking. Two attending physicians, each representing one of the disciplines, moderated the students' questions. Students, actors, and moderators were able to pause the simulation at any time by saying "time out." These pauses allowed for reflections on clinical decision-making and communication style. After each simulation, the focus was on mutual feedback between actors, students, and moderators with an emphasis on perspective change and communication. For the SARS-CoV-2 pandemic year of 2021, the training had to be held online via Zoom (Zoom Video Communications Inc., 2022).

Course Feedback

Course feedback was collected after the last day of actor-based training day with a form including four items, answered on a 5-point Likert scale: "How realistic did today's training with actors seem to you?"; "How did you feel during the training?"; "How much have you learned about yourself today?"; and "How did you feel about the actors' feedback to you?". Two open-ended questions were also asked: "what did you like about training with actors today?" and "what did you not like today in your contact with the actors?".

Self-Reported Confidence Levels

For the evaluation of pre-to-post change in student self-reported confidence levels, two separate pre- and post-questionnaires were used. The questionnaires included two simple questions related to the main learning objectives of the day, answered on a 7-point Likert scale: "How confident do you feel in assessing acute respiratory distress?" and "How confident do you feel in assessing acute abdominal symptoms?" The pre-questionnaire was distributed three days before the teaching segment, the post-questionnaire immediately after it.

Statistical Analysis

A descriptive analysis was performed on both the feedback and the pre- and post-questionnaires, reporting on frequencies. Open-ended questions were summarised without specific analysis. A one-sided Wilcoxon signed-rank test was used to compare the null hypothesis of no differences between pre- and post-evaluations for students who filled in both evaluations. The minimal detectable effect given the final sample size was calculated with a post-hoc sensitivity power analysis set at 80%. To investigate differences between students who completed both questionnaires and students who

completed only one questionnaire, a two-sided Mann-Whitney-*U* test was conducted. The level of statistical significance was set at α = .05.
RStudio, version 1.3.1093 , running R, version 4.0.2,(R Core Team, 2019) was used for the analyses. Additional R packages that were used during the analyses included tidyverse (Wickham & RStudio, 2019), dplyr (Wickham, François, et al., 2020), data.table (Dowle et al., 2019), rcompanion (Mangiafico, 2021), ggplot2 (Wickham, Chang, et al., 2020), and patchwork (Pedersen, 2020). The post-hoc sensitivity power analysis was performed using G*Power 3.1 (Faul et al., 2009).

Ethical Considerations

The Office of Research, Research Ethics & Animal Welfare, of the Swiss Federal Institute of Technology ETH Zurich granted an exemption from ethics approval retroactively, as our teaching evaluation was not considered human subject research. Students had the option of not participating in the feedback and pre- and post-questionnaires, without this decision having any influence on the relationship with the lecturers. All questionnaires were submitted completely anonymously and were distributed and collected electronically before or after the training sessions by a third party not directly involved. The raw data and statistical analysis were carried out by a third party not directly involved in the seminar days.

Results

Course Feedback

A total of 30 students provided answers to the feedback form (overall return rate: 61.2%). Figure 1 shows the answers on the 5-point Likert scales. Students described the training with the actors to be “very realistic” (70.0%) or “moderately realistic” (30.0%). They “dared to try their personal way of asking questions during the training and felt good about it” (36.7%) or “felt comfortable during the training, still have to get used to the situation” (50.0%), but some “only felt a little comfortable” (10.0%). Students also “learned a lot” about themselves (50.0%) or at least “learned moderately much” (50.0%). The feedback the actors gave was found to be beneficial for “learning a lot about their own perceptions of other people” (33.3%) or at least to be “moderately helpful” (63.3%).

Figure 1: Collected feedback from pharmacy students (N = 30) on 5-point Likert scales about the actor-based teaching segments. (A) Closeness to reality; (B) Feeling comfortable; (C) Learning about oneself; (D) Helpfulness of the feedback.

The German open-ended comments to the questions "what did you like about training with actors today?" and "what did you not like today in your contact with the actors?" are translated in the Supplementary Tables 1 & 2. Briefly, students majorly praised the realistic acting by the actors, and simultaneously noted that "they also played somewhat 'more difficult' customers" and that "when we practise with such patients, we are certainly well prepared." Comments concerning aspects students did not like primarily included difficulties in (virtual) communication: Lack of a natural communication flow ("[…] when you look after a patient as a group, it quickly comes across as questioning instead of a conversation from one person to another"), missing out on (non-verbal) personal contact, and interacting with actors in front of a group.

Self-Reported Confidence Levels

The return rates of the pre- and post-questionnaires are shown in Table 1. Both questionnaires were filled by 30 students, resulting in an overall return rate of 61.2%.

	Count (%)*
Pre-evaluation	44 (89.8)
Post-evaluation	36 (73.5)
Both	30 (61.2)

*Notes: *Student total cohort 2021: N = 49.*

Table 1: Return rate of the pre- and post-questionnaires.

Figure 2 depicts the distribution of the students' self-assessment answers on the 7-point Likert scales, stratified by pre- and post-teaching segment for both learning objectives, feeling confident in assessing acute respiratory distress and acute abdominal symptoms. Median and mean values are shown in Table 2, alongside the calculated *p*-values and effect sizes d.

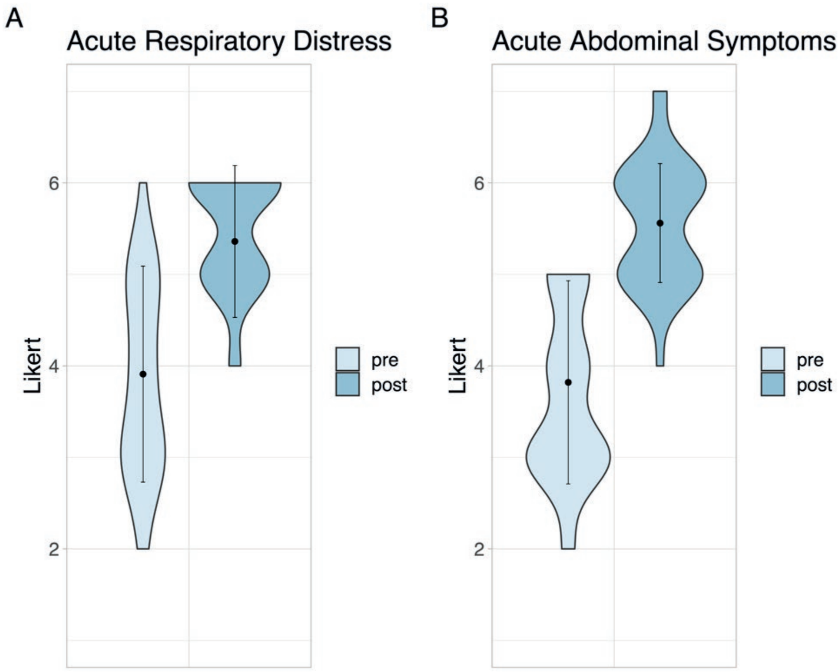

Figure 2: Changes of pharmacy students' self-reported confidence levels pre- and post-teaching segment on 7-point Likert Scales. N = 30.

	Pre-Questionnaire		**Post-Questionnaire**			
Item	**Median (IQR)**	**Mean (SD)**	**Median (IQR)**	**Mean (SD)**	**p-value***	**effect size d†**
How confident do you feel in assessing acute respiratory distress?	4 (2)	3.91 (1.18)	6 (1)	5.36 (0.83)	< .001	.85
How confident do you feel in assessing acute abdominal symptoms?	4 (2)	3.82 (1.11)	6 (1)	5.56 (0.65)	< .001	.87

*Notes: IQR = Inter-quartile range, SD = Standard deviation. *One-sided Wilcoxon signed-rank test to compare the null hypothesis of no differences between pre- and post-evaluation for 30 students who filled in both evaluations. A significant p-value (p < 0.05) indicates that there are statistically significant differences on the responses. †Pearson r correlation. Effect sizes may be interpreted as per Cohen (Cohen, 1992) r = 0.10 = weak effect, 0.25 = moderate effect, 0.40 = strong effect. The post-hoc sensitivity power analysis calculated the minimal detectable effect for our matched pre- and post-evaluation pairs to be d = .46 at a power of 80%.*

Table 2: Median and mean changes of pharmacy students' self-reported confidence levels pre- and post-teaching segment on 7-point Likert Scales. N = 30.

For symptoms of respiratory distress, the confidence levels improved from a median of 4 (inter-quartile range: 2) to a median of 6 (1) with a very strong effect size of .85.

The confidence levels for acute abdominal symptoms likewise improved from a median of 4 (2) to a median of 6 (1) with a very strong effect size of .87. The post-hoc sensitivity power analysis calculated the minimal detectable effect for our matched pre- and post-evaluation of 30 pairs to be d = .46 at a power of 80%.

Responses for both items were not statistically different in between students who completed both questionnaires and students who completed only the pre- or post-questionnaires (Mann-Whitney-*U* test, $p > 0.05$, data not shown).

Discussion

In this evaluation of an actor-based training for fifth year pre-registration pharmacy students, statistically significant improvements were observed in immediate self-reported confidence levels for triaging acute respiratory and abdominal symptoms in a fully virtual setting. Students reported feeling comfortable, thinking the simulation to be realistic, and learning about themselves with the feedback they received from the actors.

Feedback, or debriefing, enables students to reflect on their thought and decision-making process as well as on their communication style and the risks of unclear communication and misinterpretations (Crea, 2011). Debriefing is thought to be the most important learning portion of a simulation training (Crea, 2011). In the cohort presented here, students stated that the feedback from the actors was beneficial to learn about their own perceptions of people. Students also dared to try their personal way of asking questions and felt comfortable, showcasing a major benefit of simulation trainings through generating safe training environments. This daring and reflecting on communication within the teaching segment concurrently tackled important communication skills needed for patient-centred pharmaceutical care. Jacob and colleagues addressed an unfavourable pharmacist’s communication style (technical jargon, feeble responses to emotional prompts, controlling the interaction and content by using close-ended questions) by using actors for a forum theatre with re-enacted pharmacist-patient consultations as well (Jacob et al., 2019). Similarly, their actors used improvisational techniques and role-playing to generate non-scripted dialogues to increase the students’ communication and, ultimately, patient-care skills. This teaching approach was likewise well received by the students, again praising instantly received feedback. Generally, the use of actors and the possibility to leave the simulation for a short time with a "time out" has already been used in medical training. To practise interactions with adolescents, Hardoff and Schonmann trained students at a high school drama class (Hardoff & Schonmann, 2001). As in our training session, family physicians, paediatricians and gynaecologists then had the opportunity to practice in front of their peers, with the option to leave the simulation at any time. Here, too, learning successes were achieved through creative thinking and active learning, even among the young actors. Hardhoff and Schonmann were also able to show, however, that it is associated with reluctance and shame when individual participants must expose themselves in front of an audience of their colleagues. We also received one open-ended comment with the course feedback that noted this circumstance. This puts personal comfort in such an interactive seminar at odds with staffing possibilities, as group sizes would have to be reduced.

Active learning, which was at the centre of our case simulation, “engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert; it emphasizes higher-order thinking and often involves group work.” (Bonwell & Eison, 1991; Freeman et al., 2014) A meta-analysis on 225 studies investigated the effect of active teaching on student performance (Freeman et al., 2014). Active learning, varying from clicker questions and group problem-solving to workshop course designs, positively influenced student performance on examinations and reduced failure rates. Our simulations equally had positive effects on self-reported confidence levels. These findings are consistent with results from Tofil and colleagues, who similarly simulated a scenario of acute respiratory distress with a mannequin for pharmacy students, requiring the administration of albuterol to an infant (Tofil et al., 2010). Their training was shown to improve the students’ abilities to formulate a pharmacy care plan in conjunction with other health professionals or caregivers with the greatest effect on the application of knowledge. Tofil and colleagues reported on high retention rates of this knowledge, although only anecdotally through later conversations with their students. Likewise, Rushworth and colleagues from the Highland Pharmacy Education & Research Centre recently successfully used simulation trainings, of which some included mannequins, to develop confidence and competence in clinical assessment, management, prescribing, and consultation skills in advanced general practice clinical pharmacists (Rushworth et al., 2021). Their scenarios ranged from long-term conditions (e.g., chronic pain) to acute presentations (e.g., symptomatic uncontrolled diabetes) and new presentation of atrial fibrillation. Although not evaluated statistically, Rushworth’s simulation trainings also promoted improvements in self-reported confidence and competence in pre- to post questionnaires. In 2019, Deslauriers and colleagues published their study on Harvard University (Cambridge, Massachusetts) physics students’ self-reported perception of learning when engaged with an active teaching style (Deslauriers et al., 2019). Compared to a traditional, passive lecture, the students in the active teaching group enjoyed the lecture less, felt that they had learned less, and evaluated the teacher as being less effective in teaching, but later achieved better test results. These results impressively showed a disconnection between the students’ experience of learning and their actual learning. It is, hence, important that students are being prepared for teaching elements where they must actively contribute to pre-emptively address any misperceptions on its learning effectiveness. It was recommended that instructors explicitly present the value of increased cognitive efforts to their students to address this disconnection and misperception. This practice would simultaneously address a major barrier for active teaching styles, which is instructors who use an active teaching style receiving poorer evaluations than their traditional peers, despite following evidence on learning (Deslauriers et al., 2019).

Limitations

Limitations of this teaching segment evaluation mainly include its data collection. Student self-reported learning effects right after the lessons are reported. Student self-assessment reflects the students’ confidence levels, not their competency. The students’ ability to correctly perform an examination of a patient with acute respiratory distress or acute abdominal symptoms were not tested. Appropriately triaging such patient cases are only assessed later in objective structured clinical examinations (OSCEs) as part of the federal exams to become registered pharmacists. Asking the students right after the lessons may have resulted in overly positive answers, disregarding retention rates. In addition, our teaching evaluation consisted of only 30 students, resulting in a response rate of 61%. This limits the overall generalisability of our results. However, our post-hoc sensitivity analysis showed that even with such a small sample, the effects were large enough for conclusive statements on the effectiveness.

Impact

The restrictions on physically present higher education because of the SARS-CoV-2 pandemic posed challenges for teaching segments, especially the ones promoting active learning. These challenges, however, also presented opportunities to introduce and evaluate new approaches to teaching and learning. This teaching evaluation presents evidence for active teaching segments using re-enacted medical scenarios for pharmacy students, even in a virtual setting using video conferencing software. Working with actors instead of patients enabled a greater variety of clinical pictures coupled with more acute portrayal and easier scheduling, and students could practise in a more disinhibited way with different personalities of pharmacy clients. Additionally, this evidence generates thoughts on keeping some of the elements: Swiss pre-registration pharmacy students are placed in pharmacies scattered throughout the country and could benefit from distanced learning instead of having to travel to the university campus.

The fact that our students felt more confident in triage of acute symptoms after the training sessions is also important for the future of the pharmacy profession in Switzerland. The new tasks in primary care with expanded dispensing competencies require pharmacists to not only make the right medical decisions, but also dare to actively suggest billable pharmaceutical services in customer contact. In this sense, trainings such as those presented here prepare students for the Swiss pharmacy profession of tomorrow.

However, we also encourage a broader application of similar educational activities outside the pharmacy and medical professions, as the training with later customers can be applied in education to any later profession and filled with subject-specific content. Actor-based training addresses important transferable competencies according to the ETH Competence Framework (ETH Zurich, 2022). In addition to the subject-specific competencies, our acting simulation training also targeted the three other domains, method-specific, social, and personal: our students had to demonstrate (1) the ability to gather information, which then influenced decision-making and problem-solving (method-specific); (2) the ability to articulate thoughts and ideas (in lay language) and to adjust their effective communication to different contexts, whilst simultaneously having a strong, yet negotiating customer orientation with empathy (social); (3) the ability to adapt, think creatively and critically, taking on responsibility, and being self-aware and reflective (personal). We are convinced that actor-based training that promotes such a diversity of competencies should not be limited to medical and pharmaceutical study programmes.

Conclusion

The SARS-CoV-2 pandemic years of 2020 and 2021 forced universities and higher education to shift from physically present teaching and training towards virtual formats. Besides personal challenges for educators and students alike, this shift also entailed the danger of not being able to pass on important interpersonal, transferable skills to certain pharmacy student cohorts. Especially for triage, where the application of theoretical knowledge must be practised, there was a danger that the pre-registration students could not be given the same competence and the necessary self-confidence. This teaching evaluation showed the value of actor-based training, that self-confidence in triaging can also be successfully promoted virtually, and that different communication styles and dealing with different personalities can be integrated into other teaching elements.

Acknowledgement

The authors would like to thank the additional pre-registration pharmacy program coordination team members – namely Stefan Erni, and Dr. Elvan Kut Bacs – and the study director, Prof. Dr. Cornelia Halin Winter, for their kind assistance and support; the actors from drama class for their exceptional commitment and passion; the attending physicians of the Klinik St. Anna for their generous support in moderation and coordination; the department Educational Development and Technology (LET) at ETH Zurich for their support on teaching throughout the pandemic.

Bibliography

Allemann, S. S., van Mil, J. W., Botermann, L., Berger, K., Griese, N., & Hersberger, K. E. (2014). Pharmaceutical care: The PCNE definition 2013. *Int J Clin Pharm*, *36*(3), 544–555. https://doi.org/10.1007/s11096-014-9933-x

Blenkinsopp A., Bond C., & Raynor D.K. (2012). Medication reviews. *British Journal of Clinical Pharmacology*, *74*(4), 573–580. Embase. https://doi.org/10.1111/j.1365-2125.2012.04331.x

Bonwell, C. C., & Eison, J. A. (1991). *Active Learning: Creating Excitement in the Classroom. 1991 ASHE-ERIC Higher Education Reports.* ERIC. https://files.eric.ed.gov/fulltext/ED336049.pdf

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159.

Crea, K. A. (2011). Practice Skill Development Through the Use of Human Patient Simulation. *American Journal of Pharmaceutical Education*, *75*(9), 188. https://doi.org/10.5688/ajpe759188

Curley, L. E., Moody, J., Gobarani, R., Aspden, T., Jensen, M., McDonald, M., Shaw, J., & Sheridan, J. (2016). Is there potential for the future provision of triage services in community pharmacy? *Journal of Pharmaceutical Policy and Practice*, *9*(1), 29. https://doi.org/10.1186/s40545-016-0080-8

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences*, *116*(39), 19251–19257. https://doi.org/10.1073/pnas.1821936116

Dowle, M., Srinivasan, A., Gorecki, J., Chirico, M., Stetsenko, P., Short, T., Lianoglou, S., Antonyan, E., Bonsch, M., Parsonage, H., Ritchie, S., Ren, K., Tan, X., Saporta, R., Seiskari, O., Dong, X., Lang, M., Iwasaki, W., Wenchel, S., … Vaughan, D. (2019). *data.table: Extension of 'data.frame'* (1.12.8). https://CRAN.R-project.org/package=data.table

ETH Zurich. (2022). *ETH Competence Framework*. ETH Zurich. www.ethz.ch/comp-teachingstaff

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Federal Office of Public Health FOPH. (2019, January 1). *Simplified supply of medicinal products subject to prescription*. https://www.bag.admin.ch/bag/en/home/medizin-und-forschung/heilmittel/abgabe-von-arzneimitteln.html

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410. https://doi.org/10.1073/pnas.1319030111

Hardoff, D., & Schonmann, S. (2001). Training physicians in communication skills with adolescents using teenage actors as simulated patients. *Medical Education*, *35*(3), 206–210. https://doi.org/10.1111/j.1365-2923.2001.00764.x

Jacob, S. A., Larter, J., Blair, A., & Boyter, A. C. (2019). Using forum theatre to teach communication skills within an undergraduate pharmacy curriculum: A qualitative evaluation of students' feedback. *Currents in Pharmacy Teaching and Learning*, *11*(4), 373–381. https://doi.org/10.1016/j.cptl.2019.01.015

Koster, E. S., van Meeteren, M. M., van Dijk, M., van den Bemt, B. J. F., Ensing, H. T., Bouvy, M. L., Blom, L., & van Dijk, L. (2015). Patient–provider interaction during medication encounters: A study in outpatient pharmacies in the Netherlands. *Patient Education and Counseling*, *98*(7), 843–848. https://doi.org/10.1016/j.pec.2015.03.007

Kwan, J. L., Lo, L., Sampson, M., & Shojania, K. G. (2013). Medication reconciliation during transitions of care as a patient safety strategy: A systematic review. *Ann Intern Med*, *158*. https://doi.org/10.7326/0003-4819-158-5-201303051-00006

Mangiafico, S. (2021). *rcompanion: Functions to Support Extension Education Program Evaluation* (2.3.27). https://CRAN.R-project.org/package=rcompanion

Paudyal, V., Hansford, D., Cunningham, S., & Stewart, D. (2011). Pharmacy assisted patient self care of minor ailments: A chronological review of UK health policy documents and key events 1997–2010. *Health Policy*, *101*(3), 253–259. https://doi.org/10.1016/j.healthpol.2011.05.010

Paudyal, V., Watson, M. C., Sach, T., Porteous, T., Bond, C. M., Wright, D. J., Cleland, J., Barton, G., & Holland, R. (2013). Are pharmacy-based minor ailment schemes a substitute for other service providers?: A systematic review. *British Journal of General Practice*, *63*(612), e472–e481. https://doi.org/10.3399/bjgp13X669194

Pedersen, T. L. (2020). *patchwork: The Composer of Plots* (1.1.1). https://CRAN.R-project.org/package=patchwork

R Core Team. (2019). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.r-project.org/

Robertson-Steel, I. (2006). Evolution of triage systems. *Emergency Medicine Journal*, *23*(2), 154. https://doi.org/10.1136/emj.2005.030270

Rushworth, G. F., Innes, C., Macdonald, A., MacDonald, C., McAuley, L., McDavitt, A., Stewart, F., & Bruce, R. (2021). Development of innovative simulation teaching for advanced general practice clinical pharmacists. *International Journal of Clinical Pharmacy*, *43*(4), 817–824. https://doi.org/10.1007/s11096-021-01305-3

Seybert, A. L., & Barton, C. M. (2007). Simulation-based learning to teach blood pressure assessment to doctor of pharmacy students. *American Journal of Pharmaceutical Education*, *71*(3), 48–48. PubMed. https://doi.org/10.5688/aj710348

Stämpfli, D., Winkler, B. A., Vilei, S. B., & Burden, A. M. (2021). Assessment of minor health disorders with decision tree-based triage in community pharmacies. *Research in Social and Administrative Pharmacy*, *18*(5), 2867–2873. https://doi.org/10.1016/j.sapharm.2021.07.003

Tofil, N. M., Benner, K. W., Worthington, M. A., Zinkan, L., & White, M. L. (2010). Use of simulation to enhance learning in a pediatric elective. *American Journal of Pharmaceutical Education*, *74*(2), 21–21. PubMed. https://doi.org/10.5688/aj740221

Vyas, D., Ottis, E. J., & Caligiuri, F. J. (2011). Teaching Clinical Reasoning and Problem-solving Skills Using Human Patient Simulation. *American Journal of Pharmaceutical Education*, *75*(9), 189. https://doi.org/10.5688/ajpe759189

Wickham, H., Chang, W., Henry, L., Pedersen, T. L., Takahashi, K., Wilke, C., Woo, K., Yutani, H., Dunnington, D., & RStudio. (2020). *ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics* (3.3.0). https://CRAN.R-project.org/package=ggplot2

Wickham, H., François, R., Henry, L., Müller, K., & RStudio. (2020). *dplyr: A Grammar of Data Manipulation* (1.0.2). https://CRAN.R-project.org/package=dplyr

Wickham, H., & RStudio. (2019). *tidyverse: Easily Install and Load the 'Tidyverse'* (1.3.0). https://CRAN.R-project.org/package=tidyverse

Zoom Video Communications Inc. (2022). *Zoom Meetings*. Zoom Video Communications Inc. https://zoom.us

Appendix: Supplementary Data

In general, great praise to the actors, who have been very convincing in every lecture so far! You could almost feel the pain ;)
That was highly realistic! They were really very good!
Very good! Extremely fun and you learn a lot. Actors are extremely realistic.
it was very interesting
Keep it up. It is difficult for everyone, but Dr Gutzeit makes the best of it.
The confrontation is stronger. Patients are already familiar with their situation and are unlikely to be as direct because they have not been given new information. Actors can bring in character traits or moods more distinctly and alternate more easily.
It gives you the opportunity to ask questions or make assumptions that you don't feel quite sure about, and you get feedback directly. I find it a very good way to learn practical knowledge without having to be in direct "real" customer contact like in a pharmacy.
They gave a lot of input and acted very realistically. There were also different personality types.
Because it's not a real situation, you can also pause the situation, think about it and also do something wrong without consequences. It takes a little bit of the pressure off, which I liked.
Very realistic, possibility to solve special and unusual situations under the supervision of experts
They acted out the situation very well, very believably.
The fact that, like in the example, they also played somewhat "more difficult" customers, e.g. they didn't want to answer everything directly. It was played very convincingly.
Relation to reality (almost like real)
They are very real situations and I find the doctors' explanations very helpful for the concrete decision or action -> gives me security!
I think it's very good how they also work pictorially. Posture and coughing are shown very well. In general, I think it makes sense to learn in this way because the OSCE exam in September is also a role play in principle.
They played super again and especially Sven was not the easiest patient, he was very demanding and always wanted a solution immediately. When we practise with such patients, we are certainly well prepared. The cases were well chosen and exciting. Again, we learned a lot and the specialist perspective of the two guest doctors was very helpful.
The actors could also play a "more difficult" patient at times, which makes everything a bit more realistic. Usually not every client has so much patience or is open to reveal everything immediately.
The actors played very well and believably. They sometimes dodged our questions, which also happens in the pharmacy and was therefore realistic. I thought the case studies were good because they were not rare "special cases", but could also occur in this way in the pharmacy.
Very accurate portrayal of the symptoms, played believably.

It was a very informative day with very dedicated lecturers/organisers, thank you very much!
The actors offer a good middle ground between text and real patients. They try very hard and also take on sometimes difficult client characters
I think it makes sense to practise with actors, because actors can act out a "real" situation and perhaps prepare you more for an emergency situation.
Actors are very authentic

Supplementary Table 1: Translated open-ended comments from students as part of the course feedback to the question "What did you like about training with actors today?".

Nothing! Some things might have been better to watch in person but because of COVID it was not possible. The actors were just great!
Maybe (if someone then dares) it makes sense if only one student works with the actor. It struck me that no meaningful sequence happens during the questioning because other students keep asking different questions.
There was a lack of direct interaction. Difficult coordination with the other students. You don't want to interrupt each other.
It was more due to the online execution: you can't interact with the patient as you would like, you interrupt each other, connection problems, etc. I would definitely do it live as soon as it is possible again, important aspects are still lost through zoom. But the actors did a great job.
Nothing ;)
Personal contact would be nicer, but that's not because of the actors.
I found it difficult to interact with the actors in front of everyone, because in everyday life you are often more 1 to 1 with the client.
The situation was not so realistic in that you could not really build up a relationship with the patients. The interpersonal aspect is extremely important in such situations (perhaps a hand on the shoulder, sitting the patient on a chair and kneeling to him, which immediately creates a more confidential atmosphere) and was unfortunately lost via Zoom. Also, when you look after a patient as a group, it quickly comes across as questioning instead of a conversation from one person to another. But we can practise that in the pharmacy.
It's a bit more difficult about Zoom with non-verbal communication.
Direct contact on site would make the situation seem even more real and you could additionally use body language to calm the "patients". Online there are sometimes pauses where you don't know who of the students is supposed to say what and then suddenly several people speak again at the same time.
Rather unrealistic that such acute cases occur in the pharmacy, perhaps take a case in which rather inconspicuous symptoms occur but something serious is behind it.
The question rounds seem rather forced in most cases, especially when after 3-4 questions all the alarm bells ring and you would send the patient to hospital immediately. Personally, I would find it exciting if the actors came back with a

discharge prescription after a triage and reacted to our short assessment. Unfortunately, I don't know how feasible that would be.
Actors are perhaps a bit exaggerated, and help you arrive at the right result, which is not the case in everyday life.

Supplementary Table 2: Translated open-ended comments from students as part of the course feedback to the question "What did you not like today in your contact with the actors?".

Students' perceptions of active learning: Experiences from a course on urban ecological research

Fritz Kleinschroth[1]

Ecosystem Management Group, Department of Environmental Systems Sciences (D-USYS), ETH Zurich.

Abstract

Preparing the next generation to address current and future ecological challenges requires creative and collaborative ways of problem framing and solving. Active learning formats have the potential to support the development of skills needed to address these challenges. For future development of active learning formats, it is important to understand students' perceptions of different aspects of their learning experience and outcomes. This article is based on students' feedback from a practical course on urban ecological research. In small groups, students develop a hypothesis and research design, conduct fieldwork, and then analyse and present the results. After completion of the course, I collected qualitative feedback from students and then coded it to assess students' perception of their active learning experiences, separated by course framing, group work and supervision. The results show that students appreciate the independence to explore real-world problems in a supportive group atmosphere. Within group work, the division of tasks is perceived to lead to more efficiency, but at the same time hinders learning new skills if roles are distributed based on existing experience. Further challenges stem from the trade-offs between students who prefer closer supervision with pre-provided contents and those who perceive close supervision as disruptive or a lack of trust. I discuss how, according to self-determination theory, the learning climate provided by course framing, group work and supervision can strike a balance between needs for autonomy, competence, and relatedness. To improve, I suggest a predictable supervisory structure and full transparency to students about the active learning goals and challenges.

Introduction

Educating the "next generation", as the theme of this issue, means preparing students for increasingly complex challenges posed by current and upcoming global crises, ranging from pandemic response through biodiversity loss to climate change. These crises are often interlinked, have inherent trade-offs and high uncertainty, posing wicked problems that do not allow identifying clear-cut problem-framings or even unidimensional solutions (Balint et al., 2011). To allow students develop critical thinking, creative science approaches and collaborative maturity, new, transformational ways of learning are required (Baxter Magolda, 2009; DeHaan, 2011; Schneider et al., 2021). As part of that, ETH Zurich aims to foster a competence framework that supports besides subject-specific competences also method-specific, social and personal competences (ETH Zürich, 2023). Active learning is an important

[1] klfritz@ethz.ch

format to increase the range of acquired competences. Here, students steer their own learning process by defining a question or a problem and then independently develop a research approach to resolve the question or problem. Such self-defined learning processes have been shown to be a better preparation for complex challenges than more knowledge-based learning approaches (Freeman et al., 2014; J. I. Smith & Tanner, 2010; Wieman, 2014). Active engagement of students in the classroom has been proven to be highly effective for overall learning outcomes, yet students often perceive their own learning experience higher with passive teaching formats, especially if they are more familiar with such traditional learning environments (Deslauriers et al., 2019). To find out if this cognitive discrepancy also exists in the environmental sciences and how different aspects of the active learning process are perceived individually, I asked students for detailed feedback after running an active learning course.

In a practical course centred around basic ecological processes in urban ecosystems, we apply a "radical" active learning approach, which means that we intentionally leave the definition of research questions and hypotheses for the students to define. The aim of the course is to enable students to develop their own ways of creative science thinking. We assume that scientific endeavour starts with questioning the small things in environments that are assumed to be familiar places. Here, we invite students to explore patterns and processes of ecological interactions right in front of their doorsteps in and around the city of Zurich (Fig. 1). Apart from the general framing that the methods should include fieldwork on the ground and the overall time framing, we do not restrict the scientific questions, research design and analysis methods that the students apply in small groups. Yet, we do provide guidance by mentors with experience in applied ecological research. Throughout the course and especially in the final debriefing session, we foster co-learning within groups and peer-feedback across groups. With this setup, we attempt to create a student-centered learning environment (Baeten et al., 2010), inspired by flipped classroom techniques (Cho et al., 2021; Zappe et al., 2009).

Figure 1: Example project from the course, where students decided to probe a stream in the forests of Zurich to compare macroinvertebrate communities upstream and downstream of artificial structures (picture: Noah Bachmann).

While the general benefits of active learning are widely accepted, it remains unclear if certain elements of active learning processes are more appreciated by students than others. To improve my own teaching and to share those experiences with others, I asked students after the course to provide their written qualitative feedback on the course experience. I wanted to find out how students perceive their own active learning process in terms of provided structure for the creative process, and what could be improved from their points of view regarding supervision and group work. I discuss the results in the theoretical framework of self-determined learning. The key question of this qualitative research is how different aspects of the active learning process are perceived and valued by students. This information will be valuable for lecturers and teachers in multiple disciplines especially in the natural sciences.

Methods

The integrated practical field ecology is a Bachelor course in the Environmental Sciences curriculum designed to let students develop, run, and present their own ecological research project within a three-week timeframe, involving fieldwork around the city of Zurich. The course is roughly divided into a brainstorming, ideation, and design phase (first week), a fieldwork phase (second week) and an analysis and presentation phase (third week). Students run their projects in groups of three to four, each group supervised by a mentor. The course took place twice in April and May 2022, with 14 participants in the first round and 16 in the second round.

After the course, I carried out 30 voluntary, qualitative written surveys with course participants. The questions were grouped into three blocks, including general feedback, groupwork and course contents (see survey questions in Appendix). Self-reported students' perceptions are considered a useful indicator of learning processes, as they have been shown to influence learning outcomes (Lizzio et al., 2002). I intentionally omitted general identity-related questions such as gender, age and background as they were not relevant for the study questions, however, we included one question (no. 12) to allow free expression of identity-related issues that influenced the learning process from student's points of view. Responses were allowed in German and English; replies translated from German are labelled in the results. To ensure anonymity, participants were asked to upload their reply-sheets under a random name to a joint folder. While the purpose of the questionnaire was initially stated as for an assignment in the ETH course Foundations of Teaching and Learning, I later obtained written consent from all participants to allow the publication of this article.

To analyse the qualitative replies, I largely followed an inductive approach following a modern interpretation of grounded theory (Deterding & Waters, 2021), where responses to open-ended questions are coded into thematic aspects of perceived key elements of active learning and key challenges. Further, the question framing included deductive elements such as the assumption that self-determined learning is influenced by the learning climate provided by social interactions between students and the supervisory structure (Levesque-Bristol et al., 2022). Key focus of the analysis was therefore on self-confidence and preferred learning, and the enabling conditions provided by supervisors and within working groups. Given the focus of this paper on student's perception of active learning as a pedagogical method, I omitted responses that solely concerned the contents of the course.

Following a more quantitative approach, I further coded each survey if it was generally positive, neutral, or negative on a) the overall course, b) the course framing and approach, c) the groupwork and d) the supervision. These replies are reported in percentages of all participants.

Results

The students overall appreciated the active learning process. Out of the 30 replies, 71% were generally positive towards the approach, 16% neutral and 13% negative. This positive experience is mentioned in conjunction with personal motivation and creative processes that happened within the groups, especially while designing the experiment and during fieldwork. Yet, students also identified challenges that they faced related to the learning climate, the framing and creative process, supervision, and group work experiences. In context of the ETH Zurich competence framework, many of these challenges are linked to high expectations for subject- and method-specific competences but are instead part of the process to develop social and personal competences (Fig. 2). In the following sections we provide example quotes from student's responses to illustrate the specific perceptions and challenges faced by students, grouped into course framing and creative process, groupwork and supervision.

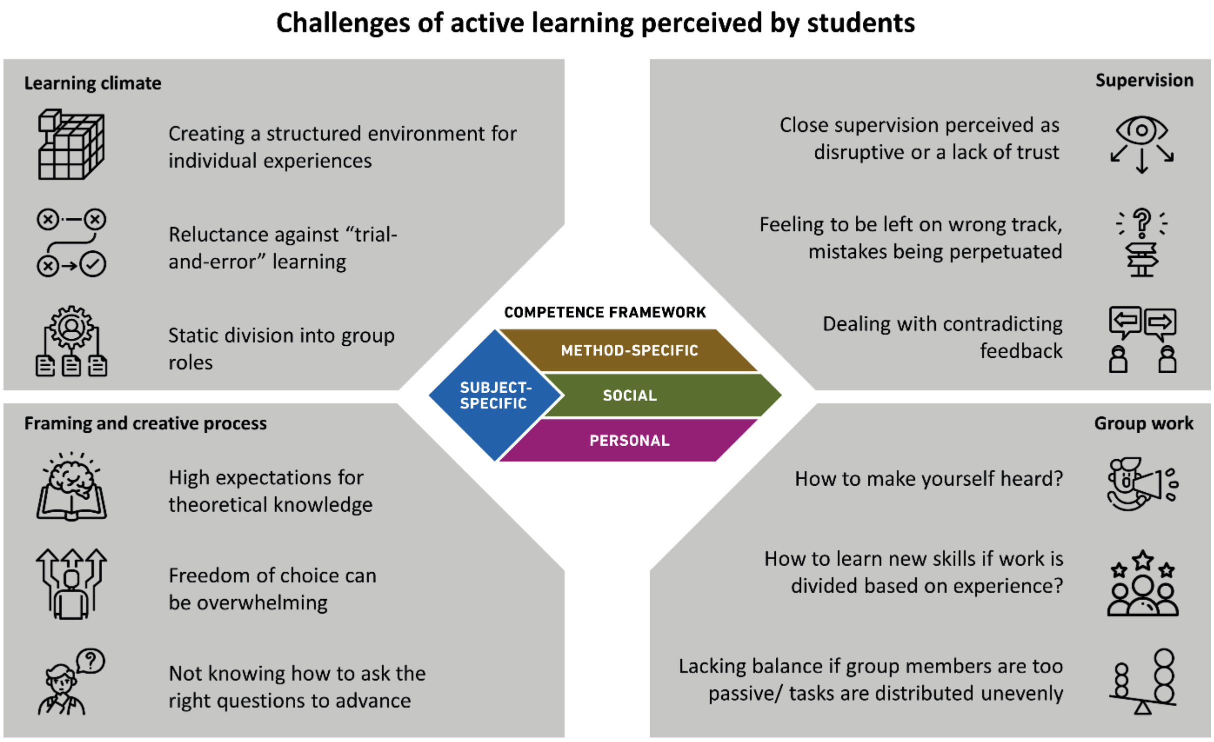

Figure 2: Overview of the coded active learning challenges based on students' replies grouped around the ETH Zurich Competence Framework[2].

Course framing and creative process

The students' replies were generally favorable about the course framing and teaching approach taken, with 80% positive, 10% neutral and 10% negative replies. A key driver of

[2] Source: www.ethz.ch/comp-teachingstaff, Images: www.flaticon.com

motivation appeared to be the independence in the work process, where students are free to decide what to do and how. This was highlighted in comments such as the following:

> *“I learn much more if I can invest time based on my own interests rather than just handling the provided contents”*

> *“In the end, I believe I learned more from this course, putting less hours of work into it. It felt less like an obligation and more like something fun to do”.*

What further drove student’s motivation was the overall change to do something different than in other lectures:

> *“It is different to our normal day when we are sitting in lectures and only have to listen to the professor. Here we could do something on our own.”*

> *“In the past the scientifical method has always been delivered to me in a very dry way («this is how it’s done.»)”*

Another set of replies concerned the benefits of applying theoretical knowledge to practice and through this start a process of reflection to find out about own abilities and gaps:

> *“I was really happy to be able to apply what I already knew and find out what I did not know yet.”*

> *“This challenged you to think of solutions yourself but if you can’t figure it out there is always someone there to help you so you don’t waste too much time on one small problem.”*

Yet, students also described challenges that they faced throughout the process. Some were challenged by the (perceived) lack of structure and theoretical knowledge and felt overwhelmed by the freedom. They perceived a need for “full picture” of theoretical knowledge and a set of available methods before being able to try things out by themselves:

> *“I personally prefer more theoretical knowledge.”*

> *“Active learning is ineffective if foundational methodological knowledge is missing.” [translated from German by the author]*

Some students also shared a feeling of being overwhelmed by the full freedom of choice and expressed the wish for more structured ways of teaching:

> *“The freedom of research topic choices we had overwhelmed and then frustrated me, instead I would have liked to have a focus or more of a guiding question to hold on to.”*

> *“Maybe there could’ve been a bit more structure. It felt like it was a bit missing but maybe it’s just that we’re not really used to this kind of work (yet)”*

Finally, there was some expression of general reluctance against what was perceived as “trial-and-error” learning:

> *“I am wondering the whole time, how I can make sense of the chaos around me and do not want this also at university. I need concrete methods and tools rather than being thrown into cold water. I am sick of more trial-and-error-learning.” [translated from German by the author]*

Group work

Students' replies about their groupwork experience, showed 71% positive, 26% neutral and 3% negative replies (i.e. one out of 30). In the group work, students appreciated being able to support each other and learn from each other. The process of spending time together in the field also had an important social function of getting to know people:

> *"Everybody helped everybody."*

> *"I felt very comfortable in my group and in the whole course. I was encouraged to say something but never forced to. So sometimes I get out of my comfort zone but it was nice to do this and say my opinion."*

> *"I had the feeling to be able to say anything if I wanted to. My opinion was never judged in a negative way"*

> *"The structure of the course made it really easy to get to know the people."*

Yet, this group process also included perceived challenges, especially regarding the division of tasks, communication and decision-making. Negotiation processes within groups were perceived as a process of self-assertion and feedback to others, making sure to have the own opinion heard while giving space to others:

> *"Some people didn't bother to say what their opinion was after they were told that something they mentioned isn't important and I think that that was sad."*

> *"When I have to give feedback, I have to understand the process, see possible mistakes but also give my feedback in a precise and understandable way."*

> *"Someone took the role of the "leader" who tried to manage the group and finalize decisions. Others were focused on the more creative, inventive part."*

> *"The quality would be better if we were more motivated. Then the team would work better together."*

Another recurring theme was the equal division and distribution of tasks. While some students perceived their form of division as positive and effective, others expressed a perception of lacking balance if group members were too passive, or tasks were distributed unevenly:

> *"That's not specific to this course, but I find it super hard if the students don't engage in the course. Here it was not as bad as usual. Students asked more questions and gave more critical feedback. They were also activated to do so. Cool!"*

> *"I think that the group put me in a position I don't usually like to take. But it was really good to get out of my comfort zone and take on a role that I normally wouldn't."*

> *"One person controlled everything and had the overview of what should be done."*

> *"I feel the roles were distributed unevenly. One or maybe two people did the bulk of the work (partially also because of language barriers with English). So, if that person or those two people were on the wrong track about something, there was virtually no counterbalance."*

Some students further mentioned that too much division of tasks can limit the learning of other group members who might become marginalized in the group process or lack confidence to take on certain tasks. An overly static division into stereotypical roles led to two contrasting perceptions: a) If someone had to take a role that they felt unsuited for, this could be perceived as inefficient. b) If work is divided exactly based on existing skills and experience, there are less perceived opportunities for students to learn new skills:

> *"There was a coordinating and reminding role, a technical role (maps, data collection) and a statistical role (R)"*

> *"Statistician, organizer, no-show-person, pressure-maker, decision-maker" [translated from German by the author]*

> *"I think I also had to take on some roles that were not necessarily my strong suit and I feel like it impacted our results negatively."*

> *"Everybody did what they already were good at, which is nice for the efficiency but maybe not great for learning new skills."*

> *"Data analysis was overtaken by one person, which is sad so the others struggled improving their own stats skills"*

Supervision

The supervision that we provided as lecturers was rated positive by 52%, neutral by 19% and negative by 29% of students. Across the range of student responses, there was a trade-off regarding the role of the supervisors or mentors: some students expected more direct feedback and guidance, others appreciated that they were not under constant supervision, while others perceived that too close supervision was disruptive or implied a lack of trust or confidence in their work:

> *"We could get help when we needed it, but also had enough space when we just wanted to discuss inside our group (aka no pressure)."*

> *"Maybe a bit more input through the course from the mentors, maybe we didn't reach out enough from our side"*

> *"Sometimes the Teaching Assistants (TA) were interrupting us right in the middle of an important design discussion."*

> *"I knew that support was there but sometimes I didn't really feel comfortable with the support given as it felt like a lack of trust in our effort was present. I know that this was probably not the case at all but it was just the mood I caught from it at some moments. Due to that I sometimes felt more comfortable trying to find solutions to a problem myself than consulting an assistant."*

The way we initiated and interacted throughout the active learning process led to some uncertainties which the students had to resolve for themselves first:

> *"When you told us at the beginning what we would have to do, I thought that it would be way harder to find ideas."*

> *"The feedback from the assistants and lecturer was very much appreciated and that I think is important also in future courses maybe just a short meetup over Zoom about the progress, but the exchange between groups not so much."*

Further responses allow to identify potential reasons for the discrepancies between student's perceptions of the supervisory structure. These could have to do with certain contradictions between feedback given by different mentors or a general feeling of being left on a wrong track, leading to a perceived perpetuation of mistakes. Another perceived reason for limited benefit from supervisors was the feeling of not knowing how to ask the "right" questions to advance:

> *"The tipps of the assessors were sometimes distracting; when we decided to do one thing, they advised us to do it differently."*

> *"The comments of our tutor mostly made sense, but often I did not understand where they should lead us to. Once we had decided what exactly we wanted to investigate, we were told to consider other things, without exactly telling us how to do it"*

> *"I feel like we did not manage to get the help we needed or desired from our mentor (not because of lack of engagement or competence but rather unclear communication or not knowing how to ask the right questions on our part)"*

Outcomes perceived from lecturer perspective

While this is generally a pleasant course to teach due to the high level of students' engagement and motivation there are also challenges from a lecturer perspective. Given the very open framing of the research questions, it happens quite frequently that the approach and methodology chosen by students are more or less outside our own research experience. This can lead to disappointment on the side of the students and an uncomfortable feeling on our side as lecturers, who are expected to be experts. We react to this by framing the course as a joint learning experience, but it is not always possible to overcome this discrepancy.

This is an ungraded course, but we generally found the final presentations by students of high quality. So far, every group has managed to identify their own hypothesis, collect data and analyse it. Naturally, the quality of the sampling designs and data produced is variable. Yet, we make it clear to students from the outset that it is not the aim to be complete in the results, but rather in the process (from start to end). We always highlight the importance of the trial-and-error approach and explicitly ask students to reflect on their own learning process during the project. They do this for example with pictures or other ways to describe and document which things did not go so well and what they think could be done better:

> *"I think all of the presentations were very engaging and interesting to listen to. They also felt very informative, so I think the delivery of the results was done very well. However, I do think that the results themselves don't have a lot of scientific value or are kind of random because they were all generated within days not months or years. Also I think everyone made a lot of mistakes during data collection (at least our group did)."*

Experiencing the learning curve together with students, and hearing about the general enjoyment of the field activities is the most rewarding part of the teaching experience. As a student framed it in the survey:

> *"I thought all the presentations were very good and was surprised by how much was achieved in the past three weeks. I think almost everyone was able to profit from this course in some way."*

Discussion

Contrary to results reported from other fields (Deslauriers et al., 2019), I find that students in our course generally showed high appreciation for the active learning approach that we chose. Complementing existing research, our qualitative approach allowed us to break down perceptions of different aspects of active learning. It shows that the course framing and structure, as well as the support within working groups was of high importance to students and generally valued higher than supervision by mentors and lecturers. A key success factor for active learning is the "buy-in" from students (Cavanagh et al., 2016). That means, the willingness of students to fully embrace the methodology strongly affects the individual learning outcomes. The willingness of all students to provide constructive feedback through the questionnaire indicates good buy-in from students. The replies illustrate a general feeling of excitement about the approach and the creative process that it triggered. Yet, individual replies showed some general reluctance and feeling of insecurity resulting from the supervisory structure that may have limited their individual buy-in and reflected on their perceived learning outcome.

The results can be interpreted in context of self-determination theory (Deci & Ryan, 2008). Self-determined learning happens in a tension field of three psychological needs that support personal wellbeing: *autonomy*, the ability to contribute to decision-making reflecting own motives; *competence*, the ability to master skills or achieve goals and *relatedness*, the feeling of connection and sense of belonging. The learning climate provided by a course determines the perceived satisfaction of these needs (Levesque-Bristol et al., 2022). Hence, active learning is most successful when all basic needs for self-determination are met. I suggest that the overall framing of the creative process (the course setup), the supervisory structure, and the groupwork are the essential levers for a course leader to control the learning climate that enables self-determined learning (Fig. 3). If *autonomy*, *competence* and *relatedness* are met within each of these factors, then the learning climate should generate good active learning outcomes.

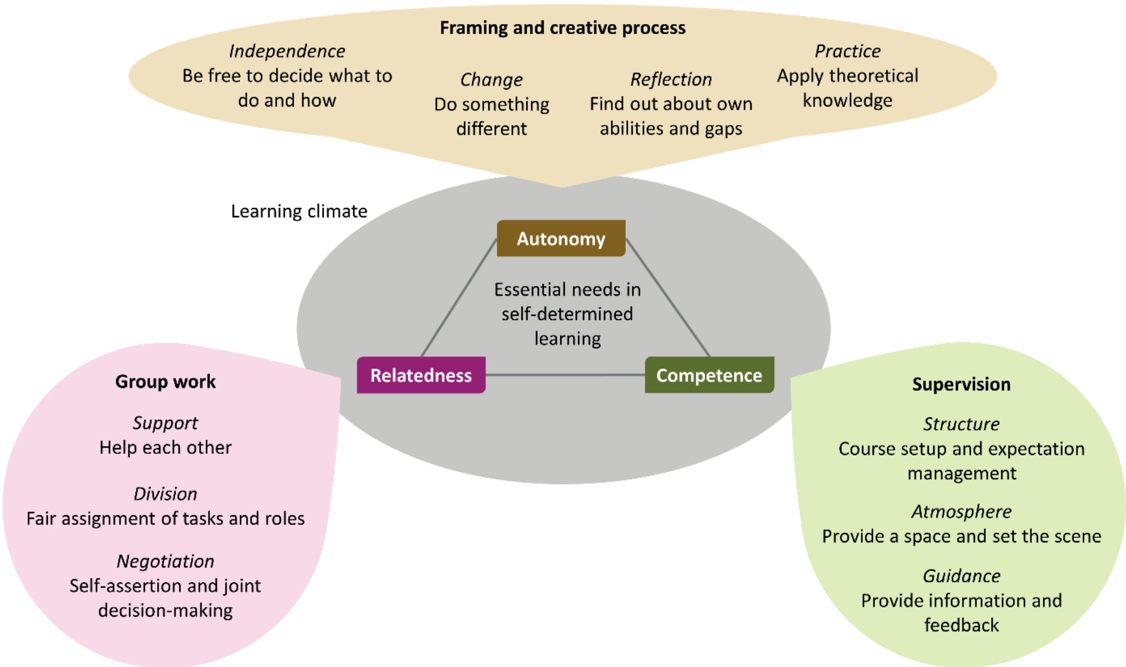

Figure 3: Foundations for active learning based on student feedback. These can be seen as the main "ingredients" for active learning, following the theoretical framework of self-determined learning (adapted from Levesque-Bristol et al., 2022) to generate a beneficial learning climate in active learning courses.

Our results show that the overall framing of the course supported the feeling of *autonomy*, the groupwork supported the feeling of *relatedness* and the supervision supported the feeling of *competence*. This led to overall positive perceptions of the active learning format and outcomes. On the *autonomy* side, independence, freedom and change from the ordinary, were frequently mentioned as highlights of the overall course. Yet, the students' perceptions of the process also reflect challenges resulting from tensions between contrasting autonomy needs that can be associated with individual preferences and experiences, but also limitations in the supervisory structure and group-dynamics.

Group work

Clearly, students can benefit from exchanging with each other through peer-instruction (Giuliodori et al., 2006). Our results show that the group work provided a strong base for the feeling of *relatedness* as an essential need in self-determined learning. This was expressed through an appreciation of the social processes and the attitude of helping each other. On the ladder of cognitive engagement from passive through active and constructive to interactive (Chi & Wylie, 2014), many of the students seem to have climbed quite high. Yet, in the tension field between *autonomy* and *competence*, students perceived several pitfalls inherent to groupwork. A well-documented issue with student's group work is related to free-riders, i.e. students who try to minimise their own effort and maximise the benefit from the overall group outcomes (Maiden & Perry, 2011). While some students perceived free-riding as a limitation for constructive discussions, others noted that this was less the case than in other courses. A more frequently mentioned (both positively and negatively) issue was the distribution of roles within the group process. It seems that most groups decided on some kind of division of tasks with the purpose to be more time efficient. This was not perceived problematic during fieldwork, but rather in the analysis phase. Here, some students reported that the statistical analysis was carried out by one person that was most familiar with the software and methods, leaving others behind with the feeling of a missed opportunity to advance their own skills. Structurally, this situation could be countered by a requirement that roles in the group must be actively rotated (Chi & Wylie, 2014), even if that may impact on the overall perceived group performance. Finally, while it has been shown that active learning settings can favour male dominance in group interactions (Aguillon et al., 2020), none of the students reported this as an issue, although the questionnaire explicitly included the possibility to report on gender or identity-related issues within group work or supervision.

Supervision

The results indicate that students clearly differ in their preferences for supervisory structures, and there is a constant tension between thriving on the independent, self-guided and peer-group working, as opposed to directed, structured, and teacher-led approaches. Related to the *competence* dimension of self-determined learning, some students expressed the wish for expert-curated content that should be provided to them in oral or written form. It has been shown that content review is often favoured over experiential learning, independent of the fact if the student has the capacity to process all the provided information or not (C. V Smith & Cardaciotto, 2011). Related to this wish for expert-led learning, we identified that some students were relatively sensitive for the coherence in guidance and instructions provided to them from different mentors. Further, there was an expectation from students that supervisors were able to give expert advice on any of the freely chosen topics and methodologies, which was not the case and - in the given format - also not realistic. Here, students expected the role of the supervisors to be simply providers of information, rather than the more complex roles of “facilitator” or “coach” which are required for problem-solving processes such as the group work in the course (Stauffacher et al., 2006). Finally, a key factor for the perception of supervision seemed to be the timing in which feedback was provided. If groups were visited on a regular base without being called up, this could be perceived as disruptive or as a lack of trust. If on the other hand consultations were provided only upon request from the students, this could lead to a feeling of getting lost in a situation where the group did not feel to be able to formulate a meaningful question. Here, a clearer supervisory structure, with co-agreed scheduled regular meetings may provide a more transparent and predictable framework.

Conclusions

Active learning is now relatively well-established in the field of environmental sciences. Feedback from students in our course showed that they are generally open for this approach and perceive benefits from it. The main challenge lies in making the process equally accessible and beneficial for everyone, involving people with contrasting expectations and learning preferences. One idea to reconcile experienced and actual learning could be to show existing research at the beginning of the course indicating that active learning generates better learning outcomes than passive learning (e.g. Deslauriers et al., 2019). Yet, we also see potential for improvement in how our course is structured and organised. We suggest that the key to successful active learning processes in groups lies in the flexibility how roles are distributed and shifted within groups during the work process, which could be steered by improved preparation and self-reflection beforehand. We further emphasize on the importance of making the supervisory structure predictable before the course which includes clear communication about what kind of mentorship and facilitation is offered and what is expected from groups. While the students feedback overall supported our “radical” active learning approach, we suggest that reliable supervision and dynamic group processes are key for improved learning outcomes. Providing guidance on group work, facilitation, and debriefing processes from the outset may help improving the supervision and group work related limitations of active learning and thrive on the benefits that many students perceive from active learning.

Acknowledgement

I thank the 30 BSc students of the integrated practical field ecology at ETH Zurich for their detailed comments on the course and their agreement to use their feedback in this publication. I further thank Jaboury Ghazoul for co-leading this course and commenting on an earlier draft of the paper. I thank Paloma Julia Martinez, Masumi Hisano, William Verbiest and Adelaide Sander for acting as mentors in the course. Two anonymous reviewers kindly provided constructive feedback to the manuscript. I finally thank the ETH Zurich ethics commission for assessing the research (approval number EK 2022-N-170).

Bibliography

Aguillon, S. M., Siegmund, G. F., Petipas, R. H., Drake, A. G., Cotner, S., & Ballen, C. J. (2020). Gender differences in student participation in an active-learning classroom. *CBE Life Sciences Education*, *19*(2), 1–10. https://doi.org/10.1187/cbe.19-03-0048

Baeten, M., Kyndt, E., Struyven, K., & Dochy, F. (2010). Using student-centred learning environments to stimulate deep approaches to learning: Factors encouraging or discouraging their effectiveness. *Educational Research Review*, *5*(3), 243–260. https://doi.org/10.1016/j.edurev.2010.06.001

Balint, P. J., Stewart, R. E., Desai, A., & Walters, L. C. (2011). *Wicked Environmental Problems: Managing Uncertainty and Conflict*. Island Press. https://books.google.ch/books?id=U6bzQqZEPiMC

Baxter Magolda, M. B. (2009). Promoting Self-Authorship to Promote Liberal Education. *Journal of College and Character*, *10*(3). https://doi.org/10.2202/1940-1639.1079

Cavanagh, A. J., Aragón, O. R., Chen, X., Couch, B., Durham, M., Bobrownicki, A., Hanauer, D. I., & Graham, M. J. (2016). Student buy-in to active learning in a college science course. *CBE Life Sciences Education*, *15*(4), 1–9. https://doi.org/10.1187/cbe.16-07-0212

Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes. *Educational Psychologist*, *49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Cho, H. J., Zhao, K., Lee, C. R., Runshe, D., & Krousgrill, C. (2021). Active learning through flipped classroom in mechanical engineering: improving students' perception of learning and performance. *International Journal of STEM Education*, *8*(1). https://doi.org/10.1186/s40594-021-00302-2

Deci, E. L., & Ryan, R. M. (2008). Self-determination theory: A macrotheory of human motivation, development, and health. *Canadian Psychology*, *49*(3), 182–185. https://doi.org/10.1037/a0012801

DeHaan, R. L. (2011). Teaching creative science thinking. *Science*, *334*(6062), 1499–1500. https://doi.org/10.1126/science.1207918

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(39), 19251–19257. https://doi.org/10.1073/pnas.1821936116

Deterding, N. M., & Waters, M. C. (2021). Flexible Coding of In-depth Interviews: A Twenty-first-century Approach. *Sociological Methods and Research*, *50*(2), 708–739. https://doi.org/10.1177/0049124118799377

ETH Zürich. (2023). *ETH Competence Framework*. www.ethz.ch/comp-teachingstaff

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Giuliodori, M. J., Lujan, H. L., & DiCarlo, S. E. (2006). Peer instruction enhanced student performance on qualitative problem-solving questions. *American Journal of Physiology - Advances in Physiology Education*, *30*(4), 168–173. https://doi.org/10.1152/advan.00013.2006

Levesque-Bristol, C., Richards, K. A. R., Zissimopoulos, A., Wang, C., & Yu, S. (2022). An evaluation of the integrative model for learning and motivation in the college classroom. *Current Psychology*, *41*(3), 1447–1459. https://doi.org/10.1007/s12144-020-00671-x

Lizzio, A., Wilson, K., & Simons, R. (2002). University students' perceptions of the learning environment and academic outcomes: Implications for theory and practice. *Studies in Higher Education*, *27*(1), 27–52. https://doi.org/10.1080/03075070120099359

Maiden, B., & Perry, B. (2011). Dealing with free-riders in assessed group work: Results from a study at a UK university. *Assessment and Evaluation in Higher Education*, *36*(4), 451–464. https://doi.org/10.1080/02602930903429302

Schneider, F., Tribaldos, T., Adler, C., Biggs, R. O., Bremond, A. De, Buser, T., Krug, C., Loutre, M., Paulavets, K., Moore, S., Norstro, A. V, Urbach, D., Spehn, E., & Wu, G. (2021). Co-production of knowledge and sustainability transformations: a strategic compass for global research networks. *Current Opinion in Environmental Sustainability*, 127–142. https://doi.org/10.1016/j.cosust.2021.04.007

Smith, J. I., & Tanner, K. (2010). Approaches to Biology Teaching and Learning The Problem of Revealing How Students Think: Concept Inventories and Beyond. *CBE-Life Sciences Education*, *9*, 1–5. https://doi.org/10.1187/cbe.09

Smith, C. V, & Cardaciotto, L. (2011). Is active learning like broccoli? Student perceptions of active learning in large lecture classes. *Journal of the Scholarship of Teaching & Learning*, *11*(1), 53–61. http://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,cookie,uid&db=ehh&AN=58601456&site=ehost-live

Stauffacher, M., Walter, A. I., Lang, D. J., Wiek, A., & Scholz, R. W. (2006). Learning to research environmental problems from a functional socio-cultural constructivism perspective: The transdisciplinary case study approach. *International Journal of Sustainability in Higher Education*, *7*(3), 252–275. https://doi.org/10.1108/14676370610677838

Wieman, C. E. (2014). Large-scale comparison of science teaching methods sends clear message. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23), 8319–8320. https://doi.org/10.1073/pnas.1407304111

Zappe, S., Leicht, R., Messner, J., Litzinger, T., & Lee, H. W. (2009). "Flipping" the Classroom To Explore Active Learning in a Large Undergraduate Course. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--4545

Appendix: Original questions

Part I: General feedback

1. What were your expectations before the course? Think about learning goals but also personal and professional experiences that you wanted to make.
   Was waren deine Erwartungen an den Kurs, bezüglich Lernzielen, aber auch persönlichen und fachlichen Entwicklungszielen?

2. What surprised you? *Was hat dich überrascht?*

3. What did you enjoy (most)? *Was hat dir (am Besten) gefallen?*

4. What was missing? *Was hat gefehlt?*

5. What should be improved? *Was könnte verbessert werden?*

6. What will you remember? *Was ist hängen geblieben?*

7. If you could restructure the overall course, how would you re-allocate the time between: a) input from lecturers, b) brainstorming, c) study design phase, d) field work, e) analysis phase, f) preparing and g) giving the presentation, f) debriefing, h) other elements?
   Wenn du den Kurs selbst strukturieren könntest, wie würdest du die Zeit neu aufteilen zwischen den verschiedenen Kurselementen; was sollte länger, was kürzer dauern?

Part II: Groupwork

8. Was the group size too big, too small or just right?
   Wie hast du die Gruppengrösse empfunden?

9. In your group, did you notice that people took different roles? Elaborate which ones.
Wie war die Rollenverteilung in deiner Gruppe, gab es unterschiedliche Zuständigkeiten auf inhaltlicher und emotionaler Ebene?

10. Did you feel you could take on a role that suited your abilities and expectations?
Konntest du eine Rolle übernehmen, die deinen Begabungen und Erwartungen entsprach?

11. Within your group, did you encounter any communication issues, and did you develop mechanisms to improve communication?
Gab es Kommunikationsprobleme und wie seid ihr mit ihnen umgegangen?

12. How comfortable did you feel personally with the support from your group, your mentor and the course leaders? Note that in this survey you do not have to give any personal information such as gender, ethnicity, sexual orientation, or personal background. Yet if you feel that any of such factors played a role in the process, feel free to state it here.
Wie sicher und unterstützt hast du dich auf persönlicher und emotionaler Ebene durch deine Gruppenmitglieder:innen, Mentor:in und Kursleiter gefühlt? Falls es einen Zusammenhang mit deiner Identität z.B. bzgl. Geschlecht, Ethnizität, sexueller Orientierung oder persönlichem Hintergrund gibt, kannst du ihn hier darlegen, musst aber keinesfalls.

13. How valuable for your overall learning process was it to work with your classmates as compared to the lecturers/mentors?
Wenn du an den gesamten Lernprozess denkst, wie hoch ist der Stellenwert des Einflusses deiner Gruppenmitglieder:innen, verglichen mit den Mentor:innen und Kursleitern?

14. If you are honest, did you effectively work more, less or exactly the amount of time that was scheduled for the course? Why do you think that was the case?
Wenn du ganz ehrlich bist, hast du effektiv mehr, weniger oder genau so viel Zeit in den Kurs investiert wie im Stundenplan vorgesehen und warum denkst du war das so?

Part III: The scientific process and urban ecological research

15. What is your opinion about the active learning approach of the course in terms of understanding a research process and applying existing ecological knowledge to a real case?
Als wie effektiv empfindest du den aktiven Lernansatz des Kurses in Hinsicht auf die Beherrschung des wissenschaftlichen Arbeitens und der Anwendung ökologischer Grundkenntnisse auf einen konkreten Fall?

16. Which part of the overall scientific process (hypothesis building, research design, field work, data analysis, presentation, etc.) do you understand better through the course?
Welcher Teil des Wissenschaftlichen Arbeitens ist klarer geworden?

17. Which part of the overall scientific process is still unclear to you?
Welcher Teil des Wiss. Arbeitens ist weiterhin unklar oder weniger klar als zuvor?

18. How would you judge the quality of the final presentations (regarding form and content) in their scientific quality and their goal to excite the listeners about the chosen scientific question?
Wie beurteilst du die Qualität der Abschlusspräsentationen im Hinblick auf wissenschaftliche Güte und das Ziel die Inhalte möglichst anschaulich und ansprechend aufzubereiten?

19. Do you feel you received sufficient feedback from classmates, mentors and course leaders that allows you to assess if you reached your own learning goals?
Hast du ausreichend Rückmeldungen auf deine Arbeit erhalten, aufgrund dessen du einschätzen kannst, ob du deine Lernziele erreicht hast?

Graduate collective in earth sciences: Promoting network building among doctoral students

Caroline Welte[1]

ETH Library, Rämistrasse 101, 8006 Zürich
Department of Earth Sciences (D-ERDW), Sonneggstrasse 5, 8092 Zürich

Adrian Gilli[2]

Department of Earth Sciences (D-ERDW), Sonneggstrasse 5, 8092 Zürich

Jordon Hemingway[3]

Department of Earth Sciences (D-ERDW), Sonneggstrasse 5, 8092 Zürich

Abstract

Doctoral students need to acquire a large skillset to meet the numerous and diverse challenges they face during their studies. Several factors can have a positive influence on how students navigate their doctoral projects independent of their supervisor's commitment. These include informal networks of doctoral students that are regarded as key components to scientific success. Although there are opportunities for building informal networks within individual research groups, few opportunities exist at the institute and department level. Several research groups within the Department of Earth Sciences (D-ERDW) gathered to launch the *Graduate Collective* in the spring semester 2022.

In a series of four seminars and ten workshops, we made use of the common thematic framework to provide 16 doctoral students with the tools and resources they need to navigate their graduate studies. Students worked closely together on the various topics in groups of different sizes, thus enabling them to build networks with co-students from related research fields. In addition, informal networking events were organized that allowed the students to deepen and stabilize their new connections with co-students. Students could earn 2 credit points for taking part in this course. We evaluate and reflect the effect of our course on network building based observations made during the course. Overall, the results underline our hypothesis that a teaching format installed between the department and group level enables participants to build networks of interpersonal support.

Introduction

In 2022, a new initiative was launched within the Department of Earth Sciences (D-ERDW) at ETH Zurich, Switzerland. A group of four lecturers designed a course—the *Graduate Collective*—with the goal of bringing doctoral students from their research groups together, as their networking opportunities had been greatly reduced during the lock-down period in 2020 and 2021. At D-ERDW, doctoral students have a range of opportunities for formal and informal networking. In this context, the students' research groups play a very important role. For

[1] caroline.welte@library.ethz.ch
[2] adrian.gilli@erdw.ethz.ch
[3] jordon.hemingway@erdw.ethz.ch

example, students participate in group meetings and group retreats. Moreover, they are typically given the opportunity to visit seminars organized within the institute or across the department. All of the above constitute formal networking opportunities. Furthermore, several informal networking events are offered to doctoral students at D-ERDW, among them the annual “doctoral retreat”, the weekly “Friday beer”, and occasionally a self-organized “doctoral excursion”. A format combining formal and informal networking opportunities on a regular basis, i.e., more than once per year, for doctoral students is so far missing at D-ERDW.

With the Graduate Collective, a new format has been launched that aims at bringing together doctoral students from different research groups. Besides providing them orientation about tools and services available at ETH Zurich, the students developed new skills and competences beyond expert knowledge. Ten instructors were invited to explore the different topics with 16 students from four research groups in weekly classes during one semester. Due to the pandemic, many of these students had little interaction before and in some cases even students from the same group were lacking interpersonal relationships. The duration of each class was between two and three teaching units (1 teaching unit = 45 minutes). Students received two credit points for regular participation and completion of homework. Even though some doctoral students in their third year participated in the course, the focus was on students who were relatively new in their doctoral studies.

Comprehensive orientation programs for doctoral students can be an effective way to ensure that students are appropriately socialized (Taub and Komives, 1998). Such programs promote equity and inclusion as they can reduce dependence on supervisors by providing the same information to all students. This is especially important as supervision is a key factor for successful and timely completion of doctoral studies (Leonard *et al.*, 2006; Kiley, 2011; McCallin and Nayar, 2012; John and Denicolo, 2013), despite the fact that in reality large disparities prevail in the quality of supervision (Ives and Rowley, 2005; Dutt, 2020). Furthermore, comprehensive orientation programs create an ideal framework for networking and, specifically, for the formation of a supportive cohort (Cooke *et al.*, 2021).

Networks play a very important role for academic success and give researchers the opportunity to meet colleagues for the exchange of knowledge. According to Kreis and Nierobisch (2016), two types of networks can be distinguished—*formal* and *informal* networks, defined as:

- **Formal networks** can be described as those with an institutionalized framework, such as the members of an institute that have a common aim.
- **Informal networks** comprise personal contacts such as friends, acquaintances, and those that fit between formal and informal contacts.

Especially for young researchers, it is important for their future career to become part of such networks. Individual opportunities may open up, e.g., for a research collaboration or a next career step (Kreis and Nierobisch, 2016). Furthermore, networks among peers provide informal learning opportunitites and support (Hasrati, 2005). In their study, Kreis and Nierobisch (2016) highlight that successful networking requires not only formal and informal networking opportunities, but also a positive attitude towards such activities.

After teaching the *Graduate Collective* for the first time in spring 2022, we reflect on the following question: *Which activities in our course are particularly effective in promoting network building among doctoral students?*

Conceptual Design of the Graduate Collective

The central focus of the *Graduate Collective* is to give learning and networking opportunities to its participants. Furthermore, a scholarly education was pursued through interaction between students, faculty, and external speakers in a series of workshops and seminars (Figure 1). The similar background of the students allowed for teaching certain generic competencies in an efficient way, particularly scientific writing where each discipline has its own conventions. Intentionally, students from different levels were included to facilitate peer-to-peer learning. General skills, i.e., scientific writing, effective communication, and presentation techniques were taught in workshop formats. For the scientific writing, we collaborated with the Language Center of ETH Zurich and the University of Zurich. For presentation techniques and communication skills, external coaches were invited. An overview of organizational units available at ETH for different concerns was given by the respective representatives in seminars. Specifically, representatives from different units of the ETH Library and from the IT Services were invited. The program for the trial phase during the spring semester 2022 is given in Table 1. By creating the time and space where students can meet in person and work on multidisciplinary competences in various formats, we enabled them to learn and connect by forming a supportive group that will potentially last beyond the course.

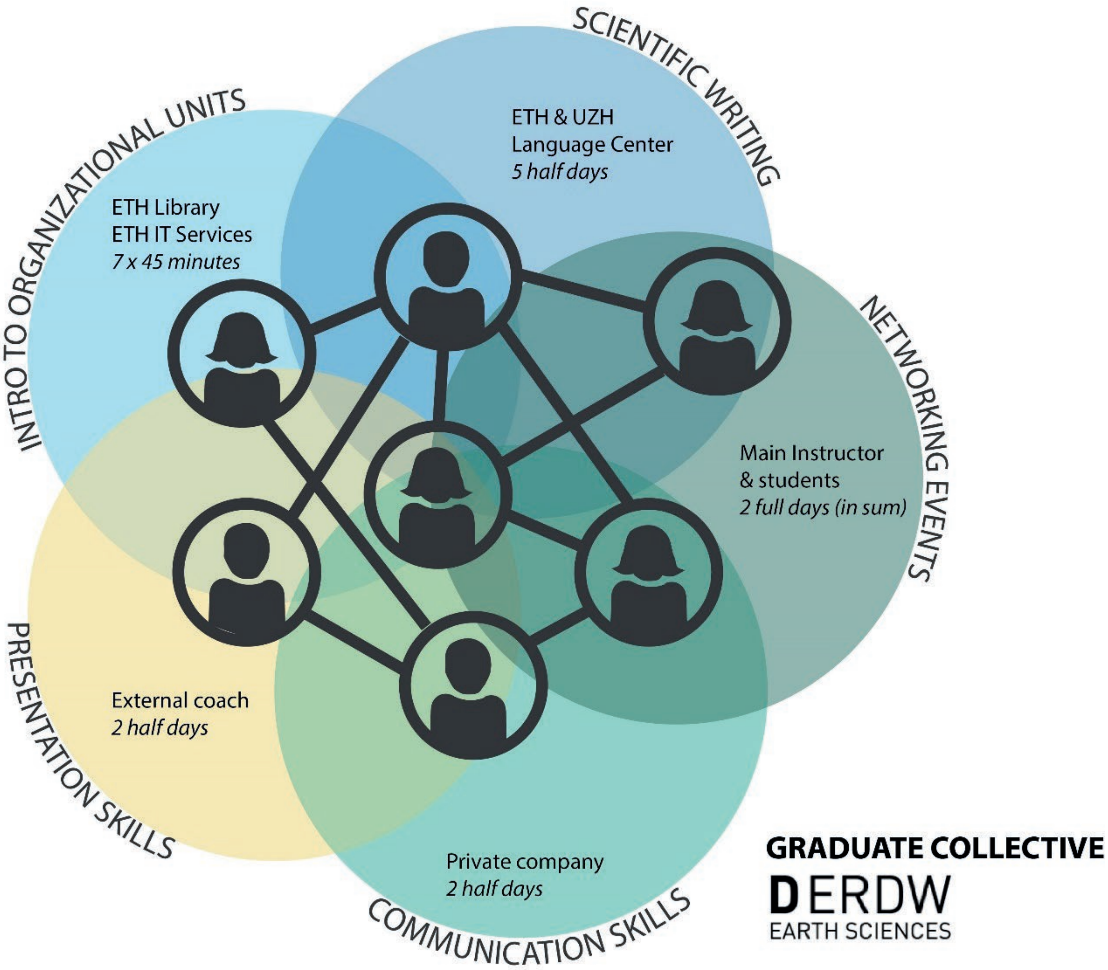

Figure 1: Overview of workshops, lectures and other activities taught in the Graduate Collective 2022

Activities promoting the formation of networks

In short, the formation of formal and informal networks was promoted through the following measures:

- **Regular meetings** during one semester served as a foundation of new networks, as students had the opportunity to see and learn about each other on a recurring basis.
- Promoting a **“safe space”** (Holley and Steiner, 2005) through interactive getting-to-know games, especially in the beginning of the semester. In the communication skills workshop, students had the chance to exchange personal experiences. These activities

facilitate interaction between participants, e.g., because common interests or issues are revealed.

- By working together on topics that affect all doctoral students equally, a **sense of community** can develop that makes later interactions between the participants more likely.
- The workshop format classes, in particular the scientific writing and the communication skills, fostered interaction on the **partner and group work** level.
- **Peer reviews** were conducted as part of the scientific writing workshop. This provided additional training in writing skills, and a sense that students can support each other also beyond this course.
- The communication skills workshop not only provided the tools necessary for **peer coaching**, but also practiced and applied the methods among themselves.
- **Informal activities** enabled deepening of already existing and formation of new networks between the participants. This comprised a group hike organized by the main lecturer and a visit to the laser tag facility organized by the students.

Methods

During the first iteration of the *Graduate Collective*, we did not employ quantitative methods for the evaluation of the course. The reflections are instead based on:

- observations of the main lecturer
- exchange with co-lecturers (e.g., during breaks, after class, and in the form of emails after the semester)
- oral exchanges with students (e.g., during breaks or after lecture and in discussions during class and randomly with several participants after the semester)

The following two criteria were used as indicators of success in promoting networking among students:

1. Quantity of interaction between students in class,
2. Quality of interaction among students in class and beyond the course.

Week	Format	Genre	Topic
1	Workshop & Homework	General	General introduction with interactive “getting to know” and networking activities
2	Seminar	Intro to organizational units / information competencies	Introduction to scientific writing
3	Workshop & Homework	Scientific Writing	Introduction: reading, grammar, resources
4	Workshop & Homework	Scientific Writing	From plan to draft, structure of a paragraph
5	Seminar	Intro to organizational units / information competencies	Introduction to IT Services and data management
6	Excursion	Informal networking Event	Hike
7	Workshop & Homework	Scientific Writing	Writing the introduction

8	Seminar	Intro to organizational units / information competencies	Introduction to ETH Library, Searching literature, Tour to Earth Science Library
9	Workshop & Homework	Scientific Writing	Writing the discussion and conclusion
10	Workshop	Communication skills	The language of Change I
11	Excursion	Informal networking Event	Laser Tag
12	Workshop & Homework	Scientific Writing	Writing abstracts and choosing titles
13	Workshop	Communication skills	The language of Change II
14	Seminar	Intro to organizational units / information competencies	Reading and Reference Management
15	Workshop	Presentation skills	Students could choose from a list of topics
16	Workshop	General	Synthesis & reflections*

*Table 1: Program for the Graduate Collective 2022. Note that this is the schedule as it was originally planned. During the course of the semester, we hosted two sessions of "Ethics in Science". The Earth Science Department participated in the pilot phase for this course that will be introduced for all ETH Departments eventually. For this trial period, integrating it into the Graduate Collective was an efficient solution, even though, in the future, this will be a stand-alone course. *The synthesis could not take place in this semester because of the "Ethics in Science" course.*

Reflections and discussion

Effectiveness of different activities in promoting student networks

In this section, different levels of activity are analyzed with respect to how much interaction they promoted among the Graduate Collective participants.

The **ice-breaker activities** of the first lesson, in particular the "speed dating", where students were asked to exchange about professional and private aspects about themselves, led to intensive interactions among the participants. Through this task, students had the chance to find out about common interests and to arouse curiosity about each other. We hypothesize that this provided points of contact for later conversations, i.e., further networking opportunities, and laid the foundations for a trustful environment. Students also confirmed that they found these activities particularly helpful for overcoming social barriers and getting engaged with co-students. Some even stated that they would have liked to see more such activities.

We assume that **regular meetings** alone, even in a steady group of individuals, are not particularly effective in promoting networks. However, in combination with other activities, we observed that they contributed to fruitful conditions for networking. For example, even though the ice-breaker activity promoted a high degree of interaction, this was limited to a short period of time. We argue that since this first event was part of a series of activities, the potential for building networks was optimally utilized in this combination.

One important factor contributing to active discussions and interactions is to create a **safe space**, as it forms the basis for students to share their views and experiences (Holley and Steiner, 2005) in front of a group. Numerous co-lecturers confirmed that they found the classes in the Graduate Collective very lively. Most notable, the "Ethics in Science" workshop required a fairly high degree of trust among the students as they were asked to prepare and present role plays about ethical dilemmas in front of the class. This activity was very successful when conducted within the Graduate Collective. In contrast, as the lecturer of the "Ethics in Science" pointed out, in a second run as a stand-alone class (2 x 3h), the level of interactivity was significantly lower.

During the four seminars, topics relevant to all students such as plagiarism, pros and cons of different literature management tools, and IT security lead to lively discussions and ultimately fostered a **sense of community** in the group. Students experienced that their concerns often apply to others as well and that for things that challenged them, some of their peers might have simple workarounds.

Partner and group work was a major part of the scientific writing workshop series. In numerous exercises, students were asked to share experiences and exchange ideas. Homework throughout the course was frequently corrected in a peer-reviewing process, either through one or two co-students, sometimes with the instruction that at least one of the referees had to be from a different research group. The lecturer confirmed that his classes greatly benefitted from the safe environment that had been created through the regular meetings and on top from the similar research themes of the students. Not only was a high number of interactions observed between participants in class, but conversations also continued during breaks outside class.

At least in one case, this resulted in an interaction of very high quality, i.e., a new scientific collaboration. The case is described in the following (names and details are change): Two doctoral students (Grace and Nina) from the same department, but different research groups meet during the first class of the *Graduate Collective*. During one of the workshops they work together on a task. Afterwards, they are asked to **peer-review** each other's assignments. Based on this experience they start having informal conversation during the breaks of the following classes. They discover that there is an overlap in their doctoral projects. Grace has knowledge on geological samples that is of great value to Nina. On the contrary, Nina is very skilled in programming and can help Grace with her data evaluation.

A comparably small number of doctoral students participated in the voluntary **fun activities**. Originally, three such events were planned. The first activity was chosen by the students through a survey and organized by the lecturer. Even though the event allowed intensive interaction and building sustainable networks, it can hardly be considered successful as only two students participated. The students were allowed to organize the second event on their own and only had to adhere to the financial guidelines as well as the instruction that the participants had to come from at least three different groups. Six students participated in in this second event.

In the two sessions focusing on communication skills students reflected on the principles of communication and learned, in small groups, the basics of peer-coaching. The level of interaction among participants was high as students were very engaged and active. Like for other classes towards the end of the semester, the number of participants was rather low, with eight (first session) and five (second session).

What are ideal networking opportunities for doctoral students?

Pilbeam, Lloyd-Jones and Denyer (2013) identified three main factors that facilitate the formation of networks among doctoral students: physical presence, shared experience, and common purpose. The challenge is to create opportunities where all three aspects can develop. In this section, the characteristic of ideal networking opportunities are discussed.

- Organizational programs offered through the institution (e.g., institute or department), such as comprehensive orientation programs, have been shown to effectively develop doctoral student networks (Pilbeam, Lloyd-Jones and Denyer, 2013). They provide the ideal framework to foster physical presence and, if suitable teaching content is offered, this can further result in shared experiences and common purpose.

- Face-to-Face interaction has been identified as a crucial component for successful networking (Pilbeam, Lloyd-Jones & Denyer, 2013).
- Non-formal networking opportunities aimed at fostering personal relationships can lead to innovative research collaborations (Kreis & Nierobisch, 2016, p. 157)
- Overcoming full schedules: doctoral students typically have very full agendas (e.g., Shin et al., 2018, p. 66). Combined with the large supply of further training and other courses at ETH Zurich, it is challenging for them to set priorities. This most likely explains the small number of students attending the voluntary “fun” excursions. Furthermore, a relatively high proportion of students frequently missed classes due to field or lab work, but also because they attended conferences. To create ideal networking opportunities for doctoral students, we hypothesize that students need to be educated about the importance of peer networks to their own careers. We also hypothesize, and in some cases have observed, that they are more engaged in the course when they feel supported or even encouraged by their supervisor.

Considerations for future teaching

For the second pass of the *Graduate Collective*, a few adaptations based on our experience from the pilot phase will be made. The course will be opened to the entire Department of Earth Sciences for two reasons: (i) to keep the number of students involved at the same level, i.e. 15 - 20, the group of doctoral students addressed must be expanded, and (ii) more students will have the chance to benefit from this program. After careful evaluation of the time investment made by students to pass the course, the amount of credit points will be increased from 2 to 3. At the same time, participation in the fun activities will be made mandatory and will have to be organized by the students. In the first lesson, we will dedicate time to increase the awareness about the importance of networks among doctoral students and how programs like the *Graduate Collective* can foster them.

To enable more interaction between the students outside of class, we plan to create a common channel (e.g., on WhatsApp) were participants will be asked to share reflections on their experiences as doctoral students. Every month, students will create two posts: one on their individual experience and one in pairs with a colleague from the course. By doing this, students will be more likely to meet outside of class and to interact even more. Through the shared experiences, we also intend to increase the shared experience and common purpose. A suitable format is the “visual expression of transitions to doctoral studies”, where photographs from experiences of the doctoral students with captions are shared within a social media channel (Elliot et al., 2020, p. 83 and p.90).

Conclusion & Outlook

A total of 16 students from four different research groups enrolled in the first run of our course. Four professors supported the new format and funding was received for two semesters. The analysis of the quantity and quality of interactions among students based on observations from lecturers and conversations with students indicate that the *Graduate Collective* fosters networking among doctoral students. In particular, the regular face-to-face meetings coupled with sharing experiences and working on common topics created numerous excellent networking opportunities. The initiative was presented at the ETH Learning & Teaching Fair 2022, where it attracted great interest. From this, we conclude that we have hit the right time with our course and can fill a gap in the offer of the Department of Earth Sciences at ETH Zurich for doctoral students. By offering education about the benefits of networks to the entire institution—from students to professors—the acceptance and engagement in a course like our Graduate Collective can be increased.

Acknowledgement

The Graduate Collective was supported by the “Projektförderung Doktorat,” an ETH program to support initiatives for doctoral students and the respective funding was granted for two semesters.

The authors would like to thank Tim Eglinton, Cara Magnabosco and Heather Stoll for their support in building this course. We would also like to thank the students from the Graduate Collective in spring semester 2022 for the numerous discussions and valuable insights in their doctoral experience. We greatly appreciate the engagement of the representatives of different organizational units from ETH Zurich and other lecturers that made the first pass of the Graduate Collective a great success: Simon Milligan, Christine Bärtsch, Andreas Müller, Fabienne Stalder, Anja Harder, Julian Dederke, Florian Lisken, Cornelia Künzle and Deborah Otuyelu. Two anonymous reviewers and the editors helped to improve this manuscript substantially, which is greatly acknowledged.

Bibliography

Cooke, M. *et al.* (2021). First-year graduate courses foster inclusion. *Nature Geoscience*, 14(8), pp. 539–540. Available at: https://doi.org/10.1038/s41561-021-00800-6.

Elliot, D.L. *et al.* (2020). The hidden curriculum in doctoral education. Springer.

Hasrati, M. (2005). Legitimate peripheral participation and supervising Ph.D. students. *Studies in Higher Education*, 30(5), pp. 557–570. Available at: https://doi.org/10.1080/03075070500249252.

Holley, L.C. & Steiner, S. (2005). Safe space: student perspectives on classroom environment. *Journal of Social Work Education*, 41(1), pp. 49–64. Available at: https://doi.org/10.5175/JSWE.2005.200300343.

Ives, G. & Rowley, G. (2005). Supervisor selection or allocation and continuity of supervision: Ph. D. students' progress and outcomes', *Studies in higher education*, 30(5), pp. 535–555.

John, T. & Denicolo, P. (2013). Doctoral education: A review of the literature monitoring the doctoral student experience in selected OECD countries (mainly UK). *Springer Science Reviews*, 1(1), pp. 41–49.

Kiley, M. (2011). Developments in research supervisor training: causes and responses. *Studies in Higher Education*, 36(5), pp. 585–599.

Kreis, Y. & Nierobisch, K. (2016). Networks - the socialization of academics. *Journal for Higher Education Development*, 11(5), pp. 145–162.

Leonard, D. *et al.* (2006). Review of literature on the impact of working context and support on the postgraduate research student learning experience. *New York, NY: The Higher Education Academy* [Preprint].

McCallin, A. & Nayar, S. (2012). Postgraduate research supervision: a critical review of current practice. *Teaching in Higher Education*, 17(1), pp. 63–74.

Pilbeam, C., Lloyd-Jones, G. & Denyer, D. (2013). Leveraging value in doctoral student networks through social capital. *Studies in Higher Education*, 38(10), pp. 1472–1489. Available at: https://doi.org/10.1080/03075079.2011.636800.

Shin, J.C., Kehm, B.M. & Jones, G.A. (2018). Doctoral education for the knowledge society. Cham: Springer.

Taub, D.J. & Komives, S.R. (1998). A comprehensive graduate orientation program: Practicing what we preach. *Journal of College Student Development*, 39, pp. 394–398.

Teaching cross-disciplinarity in the natural sciences: A case for natural philosophy

Joan Oñate Narciso[1]

University of Lleida, 25198 Lleida, Spain
Previous Address: Department of Health Sciences and Technology, Laboratory of Food Biochemistry, ETH Zurich, Schmelzbergstrasse 9, 8092 Zurich, Switzerland

Zarah Walsh-Korb[2]

Department of Chemistry, University of Basel, Mattenstrasse 24a, 4058 Basel, Switzerland
Department of Biosystems Science and Engineering, Mattenstrasse 26, 4058 Basel, Switzerland

Abstract

Interdisciplinarity in the natural sciences is a phrase one regularly hears in the context of teaching and learning, at all levels of study, from the classroom to the research environment. But what do we really understand from this term? In most cases, from the perspectives of the physical and life sciences, it is used to describe the overlap of chemistry and materials science, molecular biology and genetics, or biochemistry and biophysics, for example. While these interconnections across different fields broaden the horizon of the student, they do not always allow them to situate their learning in a broader societal context.

The natural sciences have the potential to solve many problems facing the future of our planet and these solutions come from interdisciplinary research. However, creating solutions is only part of the story. As scientists we also need to understand how to exploit our ideas, whether they should be exploited at all, and how our research fits into the world around us. To ensure future generations of scientists can both understand and solve the problems in the world around them, we need to broaden the concept of interdisciplinarity in teaching and learning. We argue that science teaching and learning must include cross-disciplinary interactions, that is, teaching a subject from the perspective of another subject, such as philosophy, or adopt different scientific philosophies to ensure the innovators of tomorrow can make well-balanced choices about the impact of their discoveries on communities and societies at large.

This approach of cross-disciplinarity is not without challenges. Integrating humanities modules with science modules in the curriculum will be beneficial, as it will introduce cross-disciplinary perspectives into teaching in the natural sciences from the bottom up. This encourages us, as teachers, to view our subjects in a more philosophical manner, and impart this deeper perspective and understanding on our students. With a specific focus on the teaching of chemistry and its cognates, subjects that have less of a modern tradition of conceptual thinking, we provide literature arguments supporting the case for philosophy in science, perspectives on how to address cross-disciplinarity in chemistry teaching, and some classroom activity suggestions to support cross-disciplinary learning.

[1] joanonate.narciso@udl.cat
[2] zarah.korb@unibas.ch

Introduction

Although the PhD has only been awarded since the early 19th century (Bourner, Bowden and Laing, 2001), it reflects the notion that scientific investigation was considered as natural philosophy and scientists as natural philosophers, following the style of the Platonic Academy (Figure 1). Natural philosophy was characterized by rigorous scientific investigation and robust scientific argumentation, the cross-over between the analytical nature of the sciences and the critical thinking of philosophy (Laplane, *et al.*, 2019). However, through the process of increasing specialization, these two domains became unentangled and began to follow independent trajectories (Gare, 2018). Today, the students we teach will become Bachelors or Masters of Science, reflecting the deep practice-oriented understanding of the field of natural science but with less focus on critical thinking and cross-disciplinary perspectives.

Figure 1: The Platonic Academy Mosaic, Villa T. Siminius Stephanus, Pompeii. Unknown author, Public Domain, Wikimedia Commons

Teaching in chemistry is highly specialized, focused on a deep practical understanding of the way chemical and biological systems behave, mastery of experimental techniques, and innovation in terms of analysis and materials design (Mulder, 2012). However, scientists spend less time questioning why these studies are important, what knowledge is gained from these investigations and what the implication of this knowledge is, both for ourselves and in a wider context (Erduran, 2013). By critically evaluating the materials that are taught to students, it is hoped that they will be better placed to encounter and react to the challenges they will face after they graduate and become practicing scientists. Let us be clear, the challenges chemistry faces today, and will continue to face in the future, are immense. The climate crisis, food and energy security, public health crises, environmental degradation, and innovations in health and biomedical sciences that come with significant ethical considerations, are major issues that cannot be addressed from a natural sciences perspective alone (Schlögl, 2010; Cole, *et al.*, 2018; Schwarzman & Buckley, 2019; World Economic Forum, 2021). Students, already from the undergraduate level, must have the capacity to critically reflect on innovations and their implications before forging a path ahead (Andreoletti & Maugeri, 2019). They must also be provided with the skills to present logical arguments for their thoughts on the subject matter and recognize good and bad reasoning when presented with scientific treatises (publications, theses, *etc.*) (Lévy & Erden, 2020). The focus today lies primarily in interdisciplinary teaching, *i.e.,* merging two fields to create new research areas (Mulder, 2012), and not on cross-disciplinary methods, *i.e.*, viewing one field from the perspective of another (Nicolini, Mengis & Swan, 2012). While interdisciplinarity is extremely valuable, it is the combination of interdisciplinarity and cross-disciplinarity approaches, referred to in the past as natural philosophy, that has the greatest chance of producing creative, critical thinkers ready for the challenges that science practice will face in the future (Park, Leahy & Funk, 2023; Meso, 2023).

Thankfully, we, the authors, are not alone in this wish to integrate a more philosophical approach to science teaching. A large number of recent articles highlight the value and advantages of bringing philosophy and natural science synergisms together (Ankeny, *et al.*, 2011; Gare, 2018; Laplane, *et al.*, 2019; Lévy & Erden, 2020; Momennejad, *et al.*, 2021). These articles highlight innovations that have come about from the cross-over between the two fields.

They propose many methods to re-integrate philosophers and scientists, and while we agree with their proposals, such as hosting philosophers in science laboratories, making space for philosophers in scientific conferences and vice-versa and co-supervising research students, we believe reintroducing philosophical methods into science teaching is the first step that needs to occur on this path to better integration of the two fields.

Through our interactions within the context of the *Fundamentals of Teaching and Learning Programme* at the ETH, the authors, one coming from the chemical sciences and one from the biological and food sciences, were introduced to each other's ideas about the place of natural philosophy in the chemical and biological sciences and decided to explore these ideas further. In this paper we introduce the concept of natural philosophy and the benefits of introducing a philosophical teaching approach in the chemistry and biology classroom. We follow this with suggestions of several learning activities that invite students to develop natural philosophical perspectives. These activities are designed to encourage students to examine their course matter using three fundamental questions grounded in philosophy (Marshall, 1973):

1. *Why are we interested in this system in the first place*?
   (Epistemology and metaphysics – the nature and scope of knowledge)
2. *Why is this system important?*
   (Logic – good and bad reasoning)
3. *What are the implications of this knowledge in a wider context?*
   (Ethics – is this the right or the wrong action to take?).

By encouraging students to reflect on course matter in this way, we are aiming to provide a grounding in natural philosophy from the bottom up. These questions translate into specific skills that students can practice with these activities, in particular, the ability to confront and criticize the *status quo* (*i.e.*, reflection and critical thinking) and the initiative to ask more conceptual questions (*i.e.*, curiosity and inquisitiveness). The following section provides the literature argument for natural philosophy, which leads into a description of the classroom activities, finishing with an analysis of the intended outcomes of the classroom activity with respect to the literature.

Examples of institutional approaches to Natural Philosophy

Many educational institutions have already recognized the value of introducing natural scientists to courses in philosophy, logic, and ethics. At ETH Zurich, for example, humanities courses are obligatory for students in the natural sciences; however, these courses run alongside natural science courses, following a more inter-disciplinary style of teaching. Students themselves are required to make the link between the two fields. We argue that students require first a grounding in the basics of both fields and then instruction on how to view each field from the perspective of the other, in a cross-disciplinary manner. Unless students practice applying philosophical skills in their chosen discipline throughout their entire academic career, these essential critical skills will be lost. At ETH Zurich, for example, ethics is not taught to undergraduate students taking the Interdisciplinary Studies or Physics courses. For food science and chemistry, the authors' own disciplines, ethics is barely introduced to students.

We propose that natural philosophy be integrated into regular science classes to maintain and further develop critical thinking, logic, and ethics skills. This is in line with the liberal arts-based education system, common in the United States and other countries with educational systems modelled on the US system, such as the Philippines. At the University of the Philippines, for example, there is a "general education" program, which is similar to the liberal arts program. The purpose of the general education program is for students to learn topics from other courses that they would not have taken if a strict "major-only courses" is followed. For example, a communication arts student will take a general mathematics course or a mathematics student will take general arts and literature courses. In addition, philosophy courses are also part of the general education electives. This way, students are provided with a well-rounded curriculum. This encourages creativity and interdisciplinary thinking, and equips students with skills that will make them more competitive in today's digital-based world and work culture.

To this end, the following two sections comprise a selection of active learning sequences that will help educators promote philosophical thinking in the chemistry classroom as a step towards, or a complement to, philosophical thinking across the educational spectrum. These active learning sequences can be integrated during introductory classes at the start of the courses so that there will not be any trade-offs with other content in the curriculum.

Classroom learning activities promoting Natural Philosophy

Part I: Introducing the active learning sequences

In this section we present some simple activities to use in the classroom, known as active learning sequences, that could be beneficial to other educators when incorporating these approaches for the first time. These sequences are designed to introduce critical thinking, logic and the implications of knowledge to the chemistry classroom, and build in complexity to allow students to probe their learning more deeply.

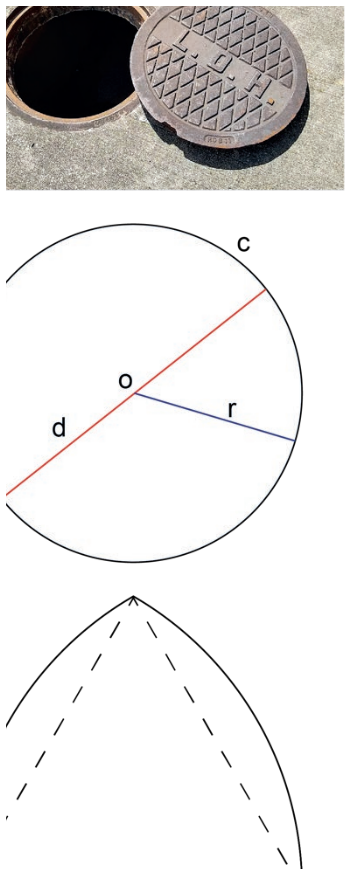

Figure 2: Manhole cover © Wikimedia Commons, CC 2.0 License (a) with examples of geometric shapes having a constant width: circle (b) and a Reuleaux triangle (c). d = diameter; o = origin; r = radius and c = circumference

Sequence 1: Abstract thinking
<u>Competences</u>: Introducing critical/abstract thinking, logic and reasoning
This activity was derived from a common mathematical problem known as Barbier's theorem (related to curves of constant width) and how that influences the design of manhole covers (Chamberland, 2016) and expanded into a critical thinking exercise in the General Education program of the University of the Philippines. We have summarized the exercise here to introduce students to abstract thinking and reasoning.
This activity seeks to use general information that the student has at their disposal (the appearance of different shapes, orientations of familiar objects in the cityscape) to begin to reflect on the decisions we make as scientists and how we must evaluate these decisions under a number of parameters before deciding whether this is an appropriate process or line of investigation.
For this task students are introduced to the manhole cover problem. (Chamberland, 2016) Students may question: "where will I apply geometry in everyday life?" They are then asked to reflect on a manhole cover. Why do they think the manhole cover is circular? Geometry tells us that as a curve of constant width, the cover will not fall in the hole (Figure 2a, b). Students are then asked to think about other shapes that would also not fall? In fact, any curve of constant width, *i.e.,* a Reuleaux triangle, or a rounded edge triangle, would not fall (Figure 2c). Thus, the students must also consider the implications of using a triangular cover instead of a round one in terms of cost, accessibility, and manufacturing? What other implications exist if the manhole cover can fall easily?

Sequence 2: Speculating about purpose

Competences: Logic and reasoning, creative thinking, abstract thinking

This active learning sequence is derived from the general aptitude tests many students encounter in high school, which are based on J.P. Guildford's divergent thinking test (also known as the alternative use test). Developed in the 1960s, this is still considered an excellent measure of creative or divergent thinking aptitude (Runco and Acar, 2012). We aim to employ it here to familiarize students with the concept of divergent thinking and speculating on the purpose of a standard object. Students are asked to list all the things they can do with a common laboratory object, *e.g.*, a weigh boat, in a fixed period of time (Figure 3). Students should be given a short period of time (5-10 mins) to list other uses, followed by a short group discussion where they discuss their list. This is a good warm-up exercise for activity 3, as it does not require subject-specific knowledge. Students will commonly be able to come up with 10-15 ideas in approximately 10 minutes, although there is no upper cap on the number of ideas! A further 10 mins can be reserved for reasoning in small groups. This could then be followed by a comparison between groups if time allows.

Figure 3: Potential uses of a standard plastic weigh boat. Image created with BioRender

Sequence 3: Rethinking the status quo

Competences: Subject specific abstract reasoning, conceptual thinking, divergent thinking, logic

Building on from sequence 2, we can combine the skills of the first two activities and expand them in a subject specific direction. This active learning sequence is designed to encourage students to think specifically about why we use certain chemical processes or materials and what other things in the world around us carry out the same functions, and could potentially replace the *status quo*. It allows students to evaluate common materials, how they function, where they are used and what other things do this, with a deeper subject specific focus. Ultimately, it should allow students to envision new ways of achieving the same end goal, that are perhaps more sustainable or economical. In the first stage, students are shown a picture of a common product or material, for example, superglue (Figure 4), with a series of questions on which to reflect.

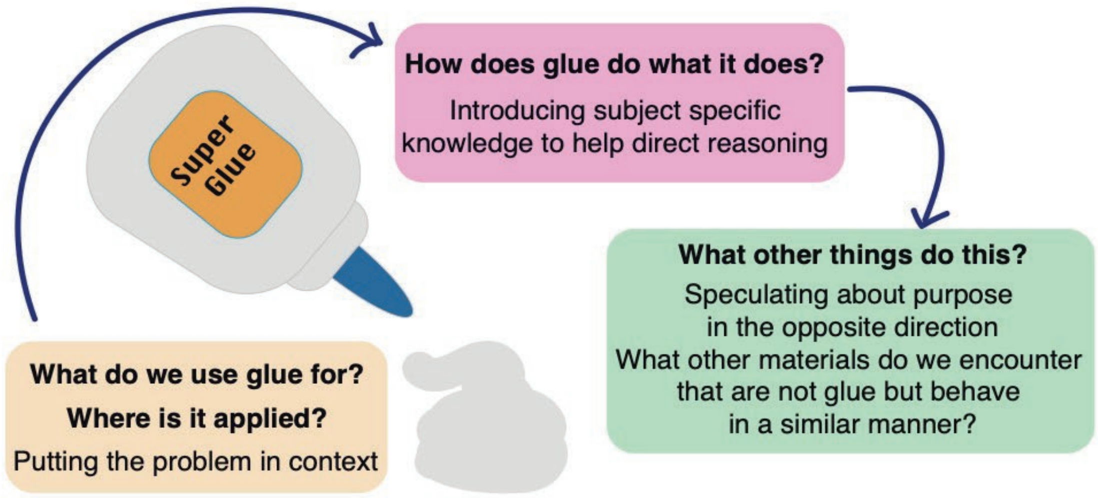

Figure 4: Impulse slide for active learning sequence 3, showing a graphic illustration of superglue with a series of questions for reflection, along with the purpose of these questions.

Students, in small groups, should reflect on the functions of the item using the orange and pink highlighted questions in Figure 4. Ideally, the instructor should provide the students with an interactive tool on which to record their answers. There are a number of different tools available for this with varying degrees of complexity (for setup) and anonymity (for participants) that must be assessed on a class-by-class basis, *e.g.*, Google Slides, Padlet or Mentimeter (Google, 2006; Goel & Piyush, 2012; Warström, 2014). This activity is designed to connect the thought processes exercised in Sequence 1 and 2. Glue is a common household item, but what does it do? and what are the external (economic, social, environmental) considerations that contributed to defining the processes we currently use to produce and use it. This is building on Sequence 1, abstract thinking and reasoning. Building on sequence 2, speculating about purpose, now we aim to fix the purpose but understand how many other ways we can achieve it. This also promotes creativity by encouraging students to reflect on all the sticky substances that are produced in nature to create a list of potential candidates. The students then return to the reason skills from Sequence 1 to understand the plausibility of replacing glue with any of the materials on their list. Essentially, this Sequence moves back and forth through the skills learned in Sequence 1 and 2 to reinforce the students learning.

Part II: Analysis of learning activities promoting Natural Philosophy

Sequence 1 is intended as an ice-breaker to introduce the student to critical reflection in the science classroom. The desired outcome here is that the student begins to question the reasoning behind common items in their everyday life and to understand that specific decisions and processes were employed to create that item and bring it into everyday use. This allows the students to gain some insight into the reasoning behind process development, which they can then transition to thinking about chemical processes in the same manner later.

Sequence 2 builds on Sequence 1 to take the student in a more specific direction, in their field of study, essentially exploring the applications of a mundane object, like a weigh boat, in non-standard applications in their field of study. In part 1 of this exercise, we are aiming to encourage students to explore their creativity, by thinking of non-standard applications for common items. In part 2 students exercise logical reasoning, as they must convince their group that this is a reasonable use for such an object. By comparing between groups, students are also given the opportunity to question the logic of their peers, a useful tool in critical thinking.

Finally in Sequence 3 we can build on the success of sequence 2. Students have been primed for out-of-the-box thinking. Questions 1-3 are for warming up, there are relatively few answers at this point because the mind is focusing on one thing and what it does. Now we can ask the students to reflect on the pros and cons of the item: Why is glue useful? What are the major issues with glue? Answers should now start to open up, there are really no right or wrong answers here, as in the previous activity, as long as they can be reasoned. Finally, we introduce the question, what other things behave like glue? Thus, the student is required to incorporate scientific information and translate this into further scientific processes. This activity was adapted from a course outline on Bioinspired Materials, developed by one of the authors. For example, a major issue in the field of biomimetics (the study of materials and processes that replicate those found in Nature) is that both students and teachers often get caught up in how we perceive an object and overlook what the object does (Perera & Coppens, 2019). Thus, when we attempt to replicate natural systems in engineering, we focus on what they look like, often resulting in poorly functioning systems as the fundamental processes may be curtailed by the focus on the appearance. Thus, it is important for students to connect to the fundamental processes of materials and their importance so that we can design better materials going forward. Anything the students can think of from the natural world that is sticky or sticks to something is an acceptable response. It might be useful to set a time limit here to allow the discussion to progress further afterwards. From these results pick the top answers, this can depend on the number of groups in the class but the top 3 responses would be useful to consider. Each team can work on one response or, depending on time and class numbers, all teams can examine all responses. Further questions can be introduced, what are the differences between the functionality of glue and the new option? What are the similarities? What would we need to do or know to replace all the glue with this new option? What would be the potential impacts of this choice? Would it be better or worse than the current options? After looking closely at the science of glue and its functionality, the students now have the opportunity to critically evaluate the feasibility, environmental impacts, cost and ethics of their choices, which is similar to the parameters being considered for making the manhole covers round, but more specifically related to their expertise as chemists.

The activities and sequences developed in the previous sections have been modified from activities we participated in as students and found particularly useful in expanding our knowledge of the particular subject area. However, these activities were developed in the context of general education and transferrable skills courses and were not used to promote learning in the chemistry or biology classroom specifically. We have adapted these experiences and activities to what we believe are the needs of learners in chemistry and biology and, which can be used to promote essential skills in natural philosophy for the next generation of chemists and biologists.

The end result of these discussions is that students gain insight into natural philosophical thinking, often referred to as design thinking (Razzouk & Shute, 2012). Importantly, they begin to evaluate options from many perspectives, particularly those outside their own field, before embarking on new processes. Furthermore, they start to make informed choices about the potential consequences of their actions before they even step into the laboratory. We believe that scientists should learn from the very beginning to philosophize their science, that is to question, criticize and analyze what they are taught and how they approach learning, and consider the consequences of their actions. Just because we can do things in the laboratory does not always mean that we should and this evaluation of the process before any work is done is key to integrating this approach in our scientific method. We must give our students the tools they need to be aware of the potential consequences of their decisions, which may have significant impact on the world around them.

It is our opinion that solutions to these challenges will come from those with the ability to confront and criticize the *status quo*. As such, students must have the capacity to critically reflect on innovations and their implications before forging a path ahead (Loeb, 2020; Brouet, 2022; Root-Bernstein & Root-Bernstein, 2022). The suggested outcomes of the activities discussed above are based on our own experiences in learning with similar activities and translating these outcomes to relevant learning outcomes for the chemistry classroom. Critical thinking, reasoning and logic, once so common in the natural sciences, are often missing from the core of natural sciences education (Gare, 2018). This paper is meant to encourage science educators to promote reflection and critical thinking in the classroom, with the aim to revitalize the natural philosophical approach.

Conclusion

So why does science need philosophy? Or more specifically, why does chemistry need philosophy? Chemistry is very much concerned with understanding why systems and processes behave the way they do. Knowing the minute details of a system is often highly regarded and encouraged in our field but such thinking is, in our opinion, useless if there is no conceptualization of how this system exists in relation to other systems, other specialties and other fields. Being exposed to natural philosophical or liberal arts teaching styles as an undergraduate encourages students to think outside the box. Through the learning sequences described in the previous sections we describe simple examples to assist educators in promoting philosophical skills in the chemistry and biology classrooms. Through sequence 1 we describe how students can be encouraged to view objects that exist in their everyday lives with abstract/critical thinking and reasoning. Sequence two introduces students to divergent thinking, logic and further enhances their reasoning skills. Finally, in sequence three we encourage students to build on these skills in a subject specific area and promotes conceptual or design thinking, to push the boundaries of the *status quo* in their area of learning. We believe that a philosophical discussion in the natural sciences is highly beneficial in highlighting how we as scientists fit into the world around us and how we must consider the possible implications that our innovations may have on the ‘equilibrium’ in our own systems.

Philosophical thinking should have a prominent place in the basic sciences; in particular, it should play a critical role in the way we teach chemistry and biology at undergraduate and postgraduate levels. Natural philosophers, like Leonardo da Vinci, Charles Darwin, Ada Lovelace and Émilie du Châtelet, were extraordinary minds of their generations and their innovations have continued to impact the world long after their time. They combined scientific experimentation with deep conceptual thinking, the bedrock of natural philosophy, and it was this combination of approaches that led them to the ideas, for which they are famous. This approach is also crucial to address scientific challenges in a dynamic context, in a world that is changing around us all the time. By giving students the tools to critically evaluate their field from the beginning, they learn to situate themselves and their specialty in the world around them, to confront the *status quo*, gain inspiration across disciplines, assess the viability of new systems and approaches, including monetary and ethical considerations, and propose alternatives to the current system, before taking any specific course of action. These future philosophical scientists, or natural philosophers, are the best tools we have to deal with challenges that currently impact the natural sciences and will continue to do so for many decades to come.

Acknowledgement

Both authors would like to thank P. Scherrer for her invaluable feedback during the conceptualization and preparation of this manuscript. ZWK acknowledges financial support from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 842043 [CatchGel]. JON acknowledges financial support from the Future Food Fellowship, ETH Zürich World Food System Center, ETH Zürich Foundation project number: ETH 2019-HE-322.

Bibliography

Andreoletti, M. & Maugeri, P. (2019). Does medicine need philosophy? *Oral Diseases*, 25(6), pp. 1419–1422. Available at: https://doi.org/10.1111/odi.13143

Ankeny, R.A., Chang, H., Boumans, M. & Boon, M. (2011). Introduction: philosophy of science in practice. *European Journal for Philosophy of Science*, 1(3), pp. 303–307. Available at: https://doi.org/10.1007/s13194-011-0036-4

Bourner, T., Bowden, R. & Laing, S. (2001). Professional Doctorates in England. *Studies in Higher Education*, 26(1), pp. 65–83. Available at: https://doi.org/10.1080/03075070124819

Brouet, A.-M. (2022). The days of the generalist are gone. Long live the specialist! *EPFL News*, 10 October. Available at: https://actu.epfl.ch/news/the-days-of-the-generalist-are-gone-long-live-the-/ (Accessed: 4 November 2022).

Chamberland, M. (2016). Why are manhole covers round? *TedEd*. Available at: https://www.youtube.com/watch?v=wDBb2_I-oC4 (Accessed: 17 March 2023)

Cole, M.B., Augustin, M.A., Robertson, M.J. & Manners, J.M. (2018). The science of food security. *npj Science of Food*, 2(1), p. 14. Available at: https://doi.org/10.1038/s41538-018-0021-9

Erduran, S. (2013). Philosophy, Chemistry and Education: An Introduction. *Science & Education*, 22(7), pp. 1559–1562. Available at: https://doi.org/10.1007/s11191-012-9526-9

Gare, A. (2018). Natural Philosophy and the Sciences: Challenging Science's Tunnel Vision. *Philosophies*, 3, p. 33. Available at: https://doi.org/10.3390/philosophies3040033

Goel, N. & Piyush, P. (2012). *Padlet*, *Padlet*. Available at: https://padlet.com/ (Accessed: 7 November 2022).

Google (2006). *Google Slides*. Available at: https://www.google.com/slides/about/ (Accessed: 7 November 2022).

Laplane, L., Mantovani, P., Adolphs, R., Chang, H., Mantovani, A., McFall-Ngai, M., Rovelli, C., Sober, E. & Pradeu, T. (2019). Why science needs philosophy. *Proceedings of the National Academy of Sciences*, 116(10), pp. 3948–3952. Available at: https://doi.org/10.1073/pnas.1900357116

Loeb, A. (2020). Advice for Young Scientists: Be a Generalist. *Scientific American Blog Network*. Available at: https://blogs.scientificamerican.com/observations/advice-for-young-scientists-be-a-generalist/ (Accessed: 4 November 2022).

Marshall, J.P. (1973). The Teacher and His Philosophy. Lincoln, Nebraska: Professional Educators Publications, Inc.

Meso, A.I. (2023). To boost disruptive science, teach researchers critical thinking. *Nature,* 614, pp.227. Available at: https://doi.org/10.1038/d41586-023-00331-7

Momennejad, I., Krakauer, J.W., Sun, C., Yezerets, E., Rajan, K., Vogelstein, J.T. & Wyble, B. (2021). The Learning Salon: Toward a new participatory science. *Neuron*, 109(19), pp. 3036–3040. Available at: https://doi.org/10.1016/j.neuron.2021.08.023

Mulder, M. (2012). Interdisciplinarity and education: towards principles of pedagogical practice. *The Journal of Agricultural Education and Extension*, 18(5), pp. 437–442. Available at: https://doi.org/10.1080/1389224X.2012.710467

Nicolini, D., Mengis, J. & Swan, J. (2012). Understanding the Role of Objects in Cross-Disciplinary Collaboration. *Organization Science*, 23(3), pp. 612–629. Available at: https://doi.org/10.1287/orsc.1110.0664

Lévy, R. & Erden, Y.J. (2020). The long life of unicorns. *Precision Nanomedicine*, 3(4), pp. 677–684. Available at: https://doi.org/10.33218/001c.17635.

Park, M., Leahy, E. & Funk, R.J. (2023). Papers and patents are becoming less disruptive over time'. *Nature*, 613, pp.138-144. Available at: https://doi.org/10.1038/s41586-022-05543-x

Perera, A.S. & Coppens, M-O. (2019). 'Re-designing materials for biomedical applications: from biomimicry to nature-inspired chemical engineering'. *Philosophical Transactions of the Royal Society A* 377(2188), article no. 20180268. Available at: https://doi.org/10.1098/rsta.2018.0268

Razzouk, R. & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research* 82(3), pp.330-348. Available at: https://doi.org/10.3102/0034654312457429

Root-Bernstein, M. & Root-Bernstein, R. (2022) *Nobel prizes most often go to researchers who defy specialization – winners are creative thinkers who synthesize innovations from varied fields and even hobbies*, *The Conversation*. Available at: http://theconversation.com/nobel-prizes-most-often-go-to-researchers-who-defy-specialization-winners-are-creative-thinkers-who-synthesize-innovations-from-varied-fields-and-even-hobbies-186193 (Accessed: 4 November 2022).

Runco, M.A. & Acar, S. (2012) 'Divergent thinking as an indicator of creative potential', *Creativity Research Journal* 24(1), pp 66-75. Available at: https://doi.org/10.1080/10400419.2012.652929

Schlögl, R. (2010) 'The role of chemistry in the energy challenge', *ChemSusChem*, 3(2), pp. 209–222. Available at: https://doi.org/10.1002/cssc.200900183

Schwarzman, M.R. & Buckley, H.L. (2019) 'Not Just an Academic Exercise: Systems Thinking Applied to Designing Safer Alternatives', *Journal of Chemical Education*, 96(12), pp. 2984–2992. Available at: https://doi.org/10.1021/acs.jchemed.9b00345

Warström, J. (2014) *Mentimeter*, *Mentimeter*. Available at: https://www.mentimeter.com/ (Accessed: 7 November 2022).

World Economic Forum (2021) *How chemistry is part of the solution to climate change – and not just part of the problem*, *World Economic Forum*. Available at: https://www.weforum.org/agenda/2021/12/green-chemistry-manufacturing-climate-change/ (Accessed: 4 November 2022).

How to train the deliberate use of intuition

Katharina Fellnhofer[1], Ursula Renold[2]

ETH Zurich, Chair of Education Systems, Department of Management, Technology and Economics (D-MTEC), Switzerland.

Abstract

We aim to investigate how to professionally train our skill at using intuition deliberately because prior research has shown that intuition has the potential to outperform the analytical mind, especially in complex and uncertain situations that will become only more frequent in the years to come. Teaching people to learn how to use intuition can be particularly decisive because it represents a crucial soft skill for the next generation of critical and creative thinkers. By applying advanced bibliometric analysis techniques in this mapping study, we systematically explore and visualize intuition research to highlight potential methods to train the skill of deliberately using intuition in the classroom. Our Web of Science data set comprises 7,680 peer reviewed documents with 253,986 references published by 166,649 authors through the end of 2021. Despite these high numbers, intuition is an underexplored scientific field characterized by methodological challenges, some of which are due to its unconscious nature. Our study offers first insights into research that can enhance the use of intuition. Our main goal is inspiring future research to help reveal intuition's unexploited educational potential, which can then stimulate new teaching initiatives.

Introduction

Tomorrow's generations will have to cope with more complex issues than we face today. According to the 2021–2024 Strategy and Development Plan of the Swiss Federal Institute of Technology Zurich (German: Eidgenössische Technische Hochschule Zürich, ETH Zürich), we are responsible for paving the way for today's young people to cope most effectively with the complex world of tomorrow. These critical and creative thinkers will have to make significant contributions to the common good and help preserve societal well-being, natural resources and the environment. This ambitious but vital goal means that skills like analysing and developing new solutions and making decisions using creative thinking will be essential. This approach supports with ETH's objective of promoting the acquisition of soft skills like entrepreneurial thinking and intuitive decision-making, social skills, leadership abilities, computational competencies and the ability to analyse complex issues.

To maximize the skills necessary for tomorrow, we must use both intuitive and analytical mindsets. Intuition represents the skill of using subconscious information in making conscious decisions (Lufityanto et al., 2016). We have many established tools to improve our analytical skills but scarcely any to train people – professionally, formally and effectively – to use intuition deliberately. Researchers studying cognitive thinking styles have so far spent much of their energy on controversial debates (Leach & Weick, 2018; Lurquin & Miyake, 2017; Wang et al., 2017) over whether intuition leads to errors (Kahneman, 2003; Tversky & Kahneman, 1973, 1974) or to superior results (Dane et al., 2011; Gigerenzer & Gaissmaier, 2011; Levitt, 2021; Waroquier et al., 2010).

[1] kfellnhofer@ethz.ch
[2] ursula.renold@mtec.ethz.ch

Despite those debates, there is scholarly agreement that intuition *can* be trained (Calvo-Porral & Lévy-Mangin, 2014; Eubanks et al., 2010; Iannello et al., 2020; Myers, 2007; Raio et al., 2012) and that we need to acknowledge and keep separate the different forms of intuition and their characteristics, such as expert or lay intuition (Kahneman & Klein, 2009; King & Clark, 2002; Rosen et al., 2010; Salas et al., 2010). For instance, expert intuition relies on domain expertise. Our effort to tap into the educational potential of the intuitive mind does not engage with these sometimes-heated debates but focuses on the need to find paths to improve intuition by gathering research that shows the clear potential to be further developed. This enables us to identify methods by which people can make better use of intuition. We are motivated by the argument that in addition to building a repertoire of analytics, we must pay appropriate attention to developing our intuition to cope with the complex and uncertain world of the future.

For decades, scholarly interest in intuition has emphasized the importance of gaining intuitive experience and expertise (Eubanks et al., 2010; Iannello et al., 2020); this is true across research domains like sports (Ferguson, 2013; Micklewright et al., 2017), security (Klein et al., 2010; Okoli et al., 2016), health (Gobet & Chassy, 2008; Quirk, 2006) and management (Bierly & Gallagher, 2007; Sadler-Smith & Shefy, 2004; Simon, 1987). Intuition's multifaceted applicability and its interdisciplinary impact are in line with ETH's Strategy and Development Plan. Although there is consensus that intuition can be improved with practice over time (Lufityanto et al., 2016; Mikels et al., 2011), precisely how to achieve that remains unclear, as does the extent to which it can be trained. Scientists have already started to train machines to decide intuitively (Gibney, 2016; *Nature*, 2016), even though we do not yet know how to train humans' intuitive decision-making. Educational policies such as those of the Organisation for Economic Co-operation and Development (OECD, 2014, 2019a,2019b, 2021) highlight that lifelong learning skills like intuition will be increasingly vital. Thus, we tackle the following research question: *How can we train our skill at using intuition deliberately?*

We have computers and machines that can replicate rational thinking, but that is the easier cognitive style. Beyond the potential shown by several traditional approaches for training intuition as a skill, new technologies have opened up promising but still largely unexploited pathways to train intuition. Thus, we focus on new training approaches like digital experiential tools (Fernández-Pérez et al., 2014; Kuo et al., 2009) that enable training intuition in a safe environment. Virtual reality (VR) tools can provide real-world exercises to intensify the effects of training (Checa & Bustillo, 2020; Jensen & Konradsen, 2018; Krokos et al., 2019; Radianti et al., 2020). VR is a graphic-based technology that provides a realistic experience viewed passively by users (Blair et al., 2021; Lampropoulos et al., 2021; Slater & Sanchez-Vives, 2016). Overall, highly controlled VR facilitates validity, reliability and generalizability (Matthews, 2018; Paschall et al., 2005; Persky & McBride, 2009). It offers an intensive experience where feedback can be provided, received and reflected on in a safe but realistic environment (Persky & McBride, 2009). This opens the possibility of enhancing skills through behavioural training interventions (Owens, 2018; von Bastian et al., 2022). Moreover, prior studies theorize – but do not empirically demonstrate – that VR can facilitate intuition (Ambinder et al., 2009; Seligman & Kahana, 2009). Overall, research shows that individuals using VR performed substantially better than those in traditional training environments (Argento et al., 2017; Schuster & Glavas, 2017; Wu et al., 2020) due to advantages like experiential learning (Persky & McBride, 2009). However, whether this outcome holds true for training intuition has not yet been studied.

The main contribution of our work is to outline possible avenues for training intuition through the use of new technologies and to advance this line of research. This is to enhance the understanding of intuition as a key research area. From a theoretical perspective, we emphasize that the complexity of intuition requires an abductive approach that applies multilinear, sense-making, and theory-building knowledge (Reichertz, 2019; Sætre & Van de Ven, 2021; Thatcher & Fisher, 2022).

Theoretical foundations

Our learning framework to enhance intuition is based on complementary theories such as behavioural learning (Shuell, 1986; Skinner, 1989) and experiential learning (Hawk, 2011; Kolb & Kolb, 2005, 2017; Temple et al., 1979), in rewards are used to show the consequences of intuitive behaviour and provide knowledge about using intuition through pattern recognition procedures.

New learning approaches like digital tools and games are increasingly popular (Fernández-Pérez et al., 2014; Checa & Bustillo, 2020). For instance, games can identify intuition and analytical thinking (Kuo et al., 2009). Some scholars describe VR as the quintessential learning aid of the 21st century (Rogers, 2019), and VR exercises are expected to have widespread impact on learning (Krokos et al., 2019). VR even has the potential to change learner behaviour according to recent literature (e.g., Checa & Bustillo, 2020; Jensen & Konradsen, 2018; Merchant, et al., 2014; Radianti et al., 2020). In VR exercises, learners receive either rewards or punishments for their decisions and can grasp the consequences of different behaviours (Shuell, 1986; Skinner, 1989). Experiential learning helps people use analytical skills to reflect on what they have undergone or witnessed (Kolb & Kolb, 2017). Generally, new technologies show the potential to develop new and effective pedagogical practices.

Methods

Ethics Information

This research complies with all relevant ethical regulations. It does not require approval by the ethics committees of ETH Zürich, as our review is built on publicly available information and does not engage with any human subjects. All materials, such as the maps, the underlying data set and our recorded conference presentation of the Academy of Management in 2022, are available online at https://osf.io/pwdsx, while peer review can be undertaken at https://osf.io/pwdsx/?view_only=1f34f1ae795148c38fe788d3229268ca.

A systematic mapping study

Because research related to intuition is underdeveloped and scattered across many disciplines (e.g., neuroscience, biology, management, education, psychology), a mapping study offers a crucial first step in analysing how to further study the deliberate training of intuition.

In this quantitatively driven, systematic mapping study, we analyse bibliographic information using statistical methods and bibliometric techniques such as co-citation mapping and bibliographic coupling (Braun, 2005; van Leeuwen, 2004). Grouping more than 90% of the relevant research by intellectually mapping connections makes bibliographic analysis highly accurate and reliable (Boyack & Klavans, 2010). In a systematic co-citation mapping study, paired or co-cited research documents are weighted and statistically scaled (Osareh, 1996; Pilkington & Teichert, 2006) to reveal invisible connections (Gmür, 2003) and enable the associations between documents to be explored (White & Griffith, 1981). To present these relationships in bibliometric maps, we use the analysis software tool VOSviewer and take advantage of a multidimensional algorithm (van Eck & Waltman, 2009; Waltman et al., 2010).

VOSviewer automatically assigns items to clusters based on bibliometric characteristics without allowing users to interfere or adjust the number of identified clusters. The researcher can only merge small clusters with larger ones[3]. Publications positioned close to one another on the map indicate connection: the greater the degree to which identical references are quoted in articles, the stronger the bibliographic link between those articles (e.g., Boyack & Klavans, 2010; Zhao & Strotmann, 2008). This algorithm has been widely implemented in

[3] For more information, please refer to the latest manual at www.vosviewer.com.

several disciplines (van Eck & Waltman, 2009, 2010, 2014). The broad scope of the intuition literature allows the clusters to be qualitatively interpreted with respect to the research question. Thus, a specific number of clusters does not necessarily have to lead to the same number of future research avenues. This approach allows us to highlight the potential of training methods that could work across disciplines because of their connections to a wide range of scholarly domains.

Bibliometric data processing

The aim of this mapping and clustering analysis is to systematically explore educational research dedicated to training intuition. We used a well-defined keyword strategy and the Web of Science database to identify peer reviewed documents published between 1990 and the end of 2021. To visualize our bibliographic mapping analysis, we took the following two key steps:

(1) *Database and search strategy*[4]. We collected all publications in Web of Science and used synonyms reflecting humans' two cognitive styles: rational decision-making, intuitive decision-making, analytical thinking, experimental thinking, linear thinking, nonlinear thinking, gut feeling, intuition and deliberation. We explicitly used both cognitive styles in our search strategy as they cannot be clearly separated when being trained in adults, especially in more recent educational tools that simultaneously train the intuitive and the analytical mind (Owens, 2018). Next, we used keywords to capture training aspects: training, enhancement, improvement and education. Finally, we used common words that refer to finding innovative solutions: technology, tool, device, VR and augmented reality (AR). Our review focuses on the potential to train intuition by taking advantage of 21st-century learning aids like digital tools, VR and games (Kuo et al., 2009). We explicitly used VR and AR in light of scholarly work predicting that those tools will be central learning technologies in the future. A total of 7,680 peer reviewed documents published through the end of 2021 were retrieved; these papers were written by 166,649 authors and contain 253,986 references.

(2) *Software tools for mapping and clustering.* To produce bibliographic co-citation maps, we used VOSviewer v. 1.6.15, an open source software package developed by van Eck and Waltman (2017). VOSviewer classified the documents into relevant clusters based on maps that we drew. Because our primary aim was to provide insights for future research, we mapped keywords used in abstracts and titles to identify key discussion clusters and authors and thus direct researchers to those authors and papers for closer inspection.

We used co-citation and bibliographic coupling maps to highlight important ongoing discussions by the most deeply engaged authors while analysing peer reviewed documents' titles and abstracts that show promise for future research paths dedicated to training intuition with the latest educational technology. In other words, we explored the clusters qualitatively with respect to our research question: How can we train our skill at using intuition deliberately? We analysed each cluster separately and in parallel to explore all avenues across clusters that might help identify and refine methods to train intuition. This approach enables us to derive suggestions for future research paths across clusters while still acknowledging highly influential documents and leading authors.

[4] Web of Science search strategy: (ALL=(rational decision-making) OR ALL=(intuitive decision-making) OR ALL=(analytical thinking) OR ALL=(experimental thinking) OR ALL=(linear thinking) OR ALL=(nonlinear thinking) OR ALL=(gut feeling) OR ALL=(intuition) OR ALL=(deliberation)) AND (ALL=(training) OR ALL=(enhancement) OR ALL=(improvement) OR ALL=(education)) AND (ALL=(technology) OR ALL=(tool) OR ALL=(device) OR ALL=(virtual reality) OR ALL=(augmented reality)); books excluded; publication year between 1990 and 2021.

Results

Figure 1 illustrates the distribution of the analysed documents from 1990 to 2021.

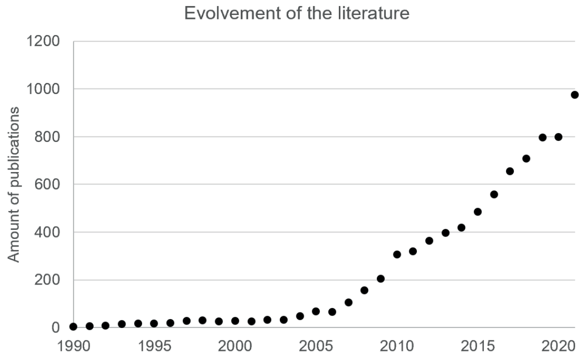

Figure 1: Time frame of the analysed documents.

Figure 2 is the first cluster map and is built on titles and abstracts. There are four main clusters, each highlighted in a different colour. The red cluster features studies related to training and aspects of methodological research. As expected, we see a lot of work related to experiments with control groups to detect how to train diverse cognitive skills. The yellow cluster depicts the literature dedicated to intuition from a medical perspective. Keywords are related to duration and time frame, which highlights the importance of long-term investigations and repeated measures. In this regard, research related to dream incubations and intuition measurements and technology related to heart rate variability and brain are discussed. The blue cluster also relates to health but focuses more narrowly on cognition and research related to the body, such as binaural audio technology that captures different beats that facilitate different brain waves. For example, an audio mix of different beats played in each ear could stimulate a particular state of consciousness – intuitive or analytical – that is linked to the brain (Berger & Turow, 2012). While beta brain waves facilitate the analytical mind, theta brain waves arouse the intuitive mind (Jovanov & Maxfield, 2012). Finally, the green cluster calls attention to experimental results related to intuition and brings organizations into the discussion. The results shown on this first map make clear how intuition touches on the full range of soft skills that are expected to be central in the rest of the 21st century.

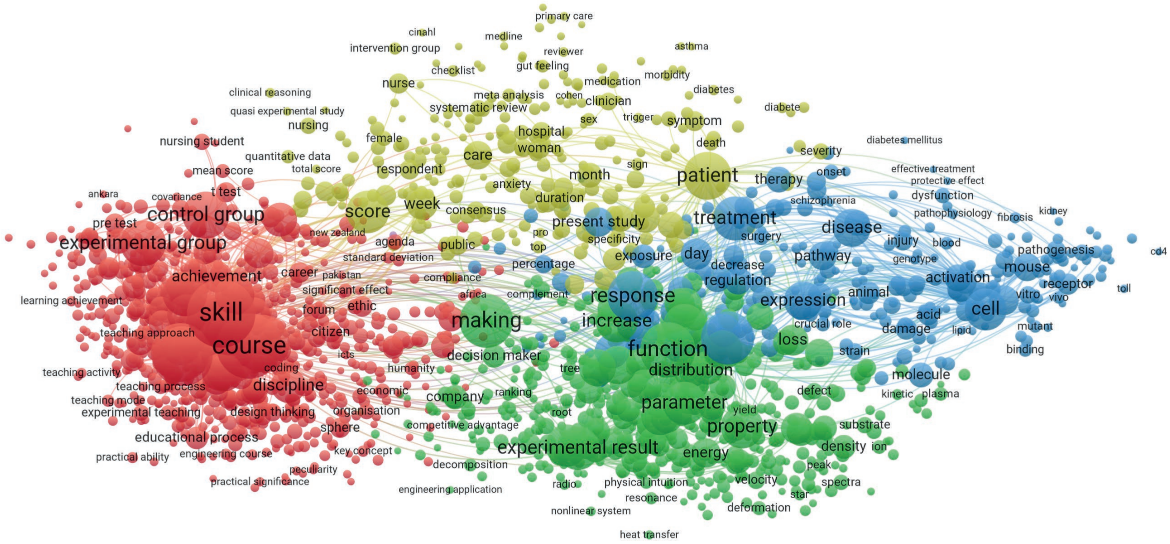

Figure 2: Cluster map based on publication titles and abstracts retrieved from Web of Science from 1990 to 2021. Terms were extracted from title and abstract fields, ignoring structured abstract labels and copyright statements. A binary counting method was used so that only the presence or absence of a term in a document mattered; the number of occurrences of a term in a document was not taken into account. The minimum number of occurrences of a term was set at 10. There are 143,244 terms,

of which 4,105 meet this threshold, and 1,863 words shape four central clusters. There are 269,365 links.

Figure 3 is the second co-citation map; it is clustered by authors who spent significant portions of their careers on intuition or related topics. Unsurprisingly, in the yellow psychological cluster we see Daniel Kahneman, whose *Thinking, Fast and Slow* (2011) is a crucial milestone in measuring intuition. There is a green cluster around John Dewey (Dewey, 1910; Dewey & Bento, 2009), a pioneer of critical thinking and experiential learning. As intuition is improved through experience and practice, it is no surprise that Dewey plays a significant role in research that deals with training intuition. Another familiar name is Jacob Cohen (1968; Wassertheil & Cohen, 1970), a leading statistician who laid important groundwork for empirical research. This highlights the need to have solid and robust measurements of intuition if we are to successfully train it. This must be kept in mind, despite the challenges posed by the subconscious and multifaceted nature of intuition. Tackling the challenge of training intuition requires new approaches and cooperation between researchers. The cluster in purple is led by Jeannette Wing (2008), who wrote a foundational work about computational thinking, which represents a universally applicable attitude and skill set that everyone – not just computer scientists – would be eager to learn and use. The red cluster is dominated by Weize Wang (W. Wang & Liu, 2013), who wrote several papers about human factors in computing systems and guided research related to highly useful technology for teachers. In this regard, VR has shown the potential of education to change behaviour (Krokos et al., 2019). Finally, the brown cluster is dedicated to creativity and led by Paul Torrance (1968, 1972), in recognition of his work on discovery and nurturing giftedness and his Torrance tests of creative thinking, which assess how creatively a child's mind works; they are often given to children to determine advanced placement or as part of entrance examinations. Torrance tests are very different from intelligence and reasoning tests that children may have already taken. Instead of traditionally taught subjects such as reading or math, these tests assess creativity. This is also very promising, as studies suggest that children who have not been taught rational skills are somehow still very skilled at intuition (Schlottmann & Wilkening, 2012). Thus, children can serve as a kind of role model because their analytical minds do not interfere as quickly or profoundly as adult minds. Overall, the ongoing debate highlights the fascinating interplay between intuition and imagination. These experts from a diverse set of fields – statistics, education, sociology, management, creativity and psychology – once again emphasize the interdisciplinary nature of training intuition, which of course creates challenges for us as intuition researchers.

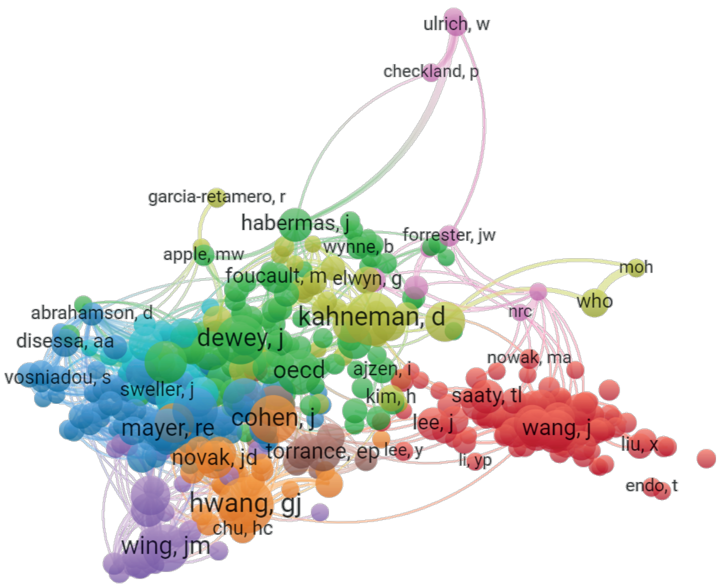

Figure 3: Cluster citation map based on authors retrieved from Web of Science from 1990 to 2021. In this co-citation analysis, the unit of analysis is a cited author. The minimum number of citations as

author was set at 20; of 166,649 authors, 513 meet that threshold. Web of Science data include only the first author of a cited document, and other authors are not considered in a co-citation analysis of authors. The full counting method was used, which means that all occurrences of a term in a document are counted. Ultimately, 505 authors were associated with 20,684 links.

Many other descriptive maps can be drawn, such as ones highlighting countries of origin and research organizations dedicated to identifying new training methods using innovative technologies for diverse cognitive skills. It is interesting but not especially surprising that the United States, Japan and China lead the academic discussion when it comes to training intuition, largely because most psychological research has been conducted in the United States, while the technological pioneers in digital education are found in China and Japan. A deeper dive into the organizations related to those countries and researchers clarifies that the University of Tokyo stands out for pioneering research in new educational technologies like VR. It is important to note that the difference between country and organization maps emphasizes the power of references to individual organizations. While the United States has numerous organizations, including Harvard, Stanford and Columbia, that play important roles in the discussion, Japan has fewer but more dominant institutions, such as the University of Tokyo and Kyoto University.

Discussion and Conclusion

We conclude by returning to our central research question: How can we train our skill at using intuition deliberately? Our Web of Science data set comprises 7,680 peer reviewed documents published between 1990 and 2021. Using the VOSviewer tool, we explored 253,986 references to 166,649 authors who study cognitive decision-making styles across research domains. Based on our review, we have identified broad areas for future research on new methodological approaches that can help deliberately train diverse cognitive skills with novel technologies. We created two key maps showing what has been done so far and who has conducted research in combining thinking styles and educational purposes, as well as promising new educational technologies like VR. We conclude our work by highlighting the methods and approaches that show the most promise but require further research. Our work on this literature review reveals the following avenues for helping to discover and refine training methods for intuition.

(1) *Interdisciplinary frameworks and real-world efforts using new educational technologies like VR.* Our first map makes clear how intuition is interwoven across diverse disciplines in research that highlight the full range of soft skills that are expected to be central in the rest of the 21st century. Research on intuition has been conducted in a wide variety of fields: statistics, education, sociology, management, creativity, psychology and more. This emphasizes the interdisciplinary nature of training intuition, which of course creates challenges. In different fields of study, VR-related research has already shown promise for future investigations because it can be applied to the real-world situations that are crucial to studying intuition. Overall, VR shows enormous promise, particularly as a tool to simultaneously train the intuitive and analytical minds (Owens, 2018). Prior work suggests that intuition can be boosted by VR (Seligman & Kahana, 2009), as our environment plays an important role in directing our behaviour (Custers & Aarts, 2010), and behaviour in VR contexts does not differ significantly from real-life scenarios (Paschall et al., 2005). VR offers several advantages to the training environment (Argento et al., 2017; Schuster & Glavas, 2017; Wu et al., 2020), including incremental learning and automatic assessment (Persky & McBride, 2009). Multiple studies have shown that individuals using VR learning technology performed substantially better than those in traditional learning environments (Argento et al., 2017; Schuster & Glavas, 2017; Wu et al., 2020). Time travel with VR represents a valuable decision-making aid that

enables people to mentally experience decision-making and receive immediate feedback in a safe environment (Persky & McBride, 2009). Finally, VR offers greater scientific rigour by facilitating external validity and generalizability (Bainbridge, 2007). For instance, the greater learning impact of VR-based educational applications and exercises (Checa & Bustillo, 2020; Jensen & Konradsen, 2018; Krokos et al., 2019) offers opportunities to train intuition in a safe environment by allowing students to reflect on the consequences of certain (changes in) behaviours. This experiential learning is expected to lead to positive changes in intuitive judgment, feelings and skills (Kolb & Kolb, 2017). However, this ability also challenges us to design virtual intuitive experiences and real-life scenarios that we can study with genuine rigour, especially with respect to their impact on the development of intuition. Success in that effort would immensely enrich the scientific discourse. While the literature indicates that VR environments are better than traditional learning contexts in many fields, to the best of our knowledge there are no solid and robust longitudinal studies that support – or refute – that claim with regard to intuition. This is an area where intuition research can learn a great deal from the health sector. As Image 2 shows, there is immense research on intuition in nurses. In this discipline, the patient is at the centre because the patient is the person at risk. This also highlights that intuition is more reliable when facing risks or operating in critical or even life-threatening contexts (Hoffrage & Marewski, 2015; Kermarrec & Bossard, 2014; Klein et al., 2010; Okoli et al., 2016). The insights presented here could help prepare other research frameworks and teaching methods that focus on risky situations to increase the power to train intuition.

(2) *Other creative technologies and devices*. The publications depicted in Image 2 highlight other new technologies that could stimulate certain conscious states that simultaneously facilitate creativity and train intuition. For example, binaural audio technology (Berger & Turow, 2012) uses different beats to activate different brain waves and appears to offer an innovative way to train intuitive decision-making. This concept is partly driven by research on computational thinking (e.g., Wing, 2008) and creative tests (e.g., Torrance, 1968, 1972). Several wearable electronic devices have been discussed in terms of assessing intuition, especially in health and medicine research. These devices can explore and exploit the creative potential of dreams (Haar Horowitz et al., 2020) by automatically generating serial auditory dream incubations at sleep onset and thus facilitate imagination and creativity, both of which are connected to intuition. Others tools achieve synchronization between heart and brain through heart rate variability (e.g., Childre et al., 2000), though this approach has come in for criticism (Hagen-Foley, 2005). Of course, many other tools show the potential to facilitate intuitive innovative thinking and open new experimental avenues and novel teaching methods.

(3) *Advanced methodological approaches.* As statistically robust analyses are crucial for any research dedicated to either analytic or intuitive thinking styles, we conclude that there is immense room for methodological improvement when exploring the potential to train intuition. Overall, we need more short- and long-term empirical studies that employ both cross-sectional and longitudinal approaches and take advantage of highly controlled experiments in real-world settings or carry out field experiments. Moreover, mixed (pre and post) designs that combine within- and between-subject experiments and qualitative and quantitative methods, including traditional approaches like focus groups and interviews, could profoundly enrich the academic discourse. In this regard, VR studies can offer greater scientific rigor (Bainbridge, 2007). Overall, we conclude that beyond traditional methods like behavioural measurements and self-reports, we need to come as close to the real world as possible to prepare tomorrow's students to succeed by using their analytical skills and to excel by using their intuitive skills.

This systematic bibliometric mapping and visualization study offers first insights into and inspiration for how to train intuition, especially at pioneering higher education institutions like ETH Zurich. Moreover, it seeks to stimulate future empirical research and practice to explore methods that can help develop advanced teaching methods. However, due to the sheer breadth of intuition, the present study has certain limitations.

Limitations

The aim of this work was to provide insights into how research could move forward to identify and enhance methods to train intuition. It is thus a first step on a long path and seeks above all to inspire future work in this direction. We have consolidated the relevant research that has been conducted to date; due to the nature of intuition, that scholarship is deeply interdisciplinary. We do not claim to have offered a full picture of intuition or how diverse cognitive skills can be trained with new technologies. Rather, we present a first review that serves to light the way to the next steps on the research path. We only touch on the most important, interesting and promising highlights of a highly diverse, vibrant and growing interdisciplinary topic. Our main aim is to inspire future research work.

Finally, we based our work on relevant keywords for the topic to ensure a comprehensive search. We identified several variations of keywords, synonyms, and related concepts. However, we note that further reviews with other keywords could lead to broader or narrower results. We have chosen the keywords that most closely reflect the current state of intuition training; of course, we encourage researchers to expand on this initial attempt.

Theoretical implications

Our work highlights that, on the theoretical level, it is crucial to apply multi-lens, sense-giving and theory-building knowledge (Reichertz, 2019; Sætre & Van de Ven, 2021; Thatcher & Fisher, 2022). The learning framework to enhance intuition could be based on complementary theories such as behavioural learning (Shuell, 1986; Skinner, 1989) and experiential learning (Hawk, 2011; Kolb & Kolb, 2005, 2017; Temple et al., 1979). However, more detail is needed, because the exact mechanisms by which those theories could contribute to a new theory focused on intuition training are not yet clear.

Following Carver's recommendations (1972, 1974; Carver & Darby, 1972), developing a training method based on robust measurement requires careful attention to within-subject dimensions of growth. To empirically evaluate any training method’s validity, evidence relative to its sensitivity to growth is essential. In line with Carver (1974), evidence for the validity of any training measurement needs to be delivered across a diverse set of studies. Future research should be mindful that training is evaluated by performance growth and therefore must be designed so that results are meaningful without reference to self, rather than relying on comparisons with the performance of others. These are baseline requirements for any technology dedicated to an educational setting that will clearly be challenging.

Practical implications

From a practical perspective, our work looks forward, exploring how to support tomorrow’s generations tackle complex problems by strengthening their intuition. The next generation of critical and creative thinkers will need to manoeuvre intuitively in highly complex situations to juggle the common good and the preservation of societal well-being, natural resources and the environment. In this context, intuition as a soft skill shows the potential to support people in analysing and developing new solutions and making decisions by using creative thinking. Highly realistic virtual worlds as educational tools offer unparalleled opportunities for both students and teachers to train their skills in a safe environment. For instance, intuition supports entrepreneurial thinking in risky situations, social skills related to health issues (Hoffrage & Marewski, 2015; Okoli et al., 2016), leadership abilities to manage humans and their emotions most effectively and the ability to analyse complex issues without knowing all the parameters. Research on intuition and experiments that include educators in intuition training could help future leaders navigate complex and uncertain environments and use intuition to make the best decisions possible (Gigerenzer & Gaissmaier, 2011; Johnson & Raab, 2003; Levitt, 2021;

Mousavi & Gigerenzer, 2014; Todd & Gigerenzer, 2007; Waroquier et al., 2010). Particularly in the face of risk and critical incidents, intuition has proven to be a fruitful resource even if it cannot always be explained in detail.

Acknowledgement

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 882168.
A prior version of this article has been presented at the Australian Centre for Entrepreneurship Research Exchange 2022 and the Academy of Management Conference in 2022. We would like to thank all participants for their valuable comments.

Bibliography

Ambinder, M. S., Wang, R. F., Crowell, J. A., Francis, G. K., & Brinkmann, P. (2009). Human four-dimensional spatial intuition in virtual reality. *Psychonomic Bulletin and Review*, *16*(5), 818–823. https://doi.org/10.3758/PBR.16.5.818

Argento, E., Papagiannakis, G., Baka, E., Maniadakis, M., Trahanias, P., Sfakianakis, M., & Nestoros, I. (2017). Augmented cognition via brainwave entrainment in virtual reality: An open, integrated brain augmentation in a neuroscience system approach. *Augmented Human Research*, *2*(1), 3. https://doi.org/10.1007/s41133-017-0005-3

Bainbridge, W. S. (2007). The scientific research potential of virtual worlds. *Science*, *317*(5837), 472–476. https://doi.org/10.1126/science.1146930

Berger, J., & Turow, G. (2012). Music, science, and the rhythmic brain: Cultural and clinical implications. In *Music, Science, and the Rhythmic Brain: Cultural and Clinical Implications* (pp. 1–215). https://doi.org/10.4324/9780203805299

Bierly, P. E., & Gallagher, S. (2007). Explaining Alliance Partner Selection: Fit, Trust and Strategic Expediency. *Long Range Planning*, *40*(2), 134–153. https://doi.org/10.1016/j.lrp.2007.03.001

Blair, C., Walsh, C., & Best, P. (2021). Immersive 360° videos in health and social care education: a scoping review. *BMC Medical Education*, *21*(1). https://doi.org/10.1186/s12909-021-03013-y

Boyack, K. W., & Klavans, R. (2010). Co-citation analysis, bibliographic coupling, and direct citation: Which citation approach represents the research front most accurately? *Journal of the American Society for Information Science & Technology*, *61*(12), 2389–2404. https://doi.org/10.1002/asi.21419

Braun, T. (2005). *Handbook of quantitative science and technology research. The use of publication and patent statistics in studies of S&T systems*. Springer.

Calvo-Porral, C., & Lévy-Mangin, J. P. (2014). Private label brands: Major perspective of two customer-based brand equity models. *International Review of Retail, Distribution and Consumer Research*, *24*(4), 431–452. https://doi.org/10.1080/09593969.2014.890953

Carver, R. P. (1972). Reading tests in 1970 versus 1980: Psychometric versus edumetric. *The Reading Teacher*, *26*(3), 299–302.

Carver, Ronald P. (1974). Two dimensions of tests: Psychometric and edumetric. *American Psychologist*, *29*(7), 512–518. https://doi.org/10.1037/h0036782

Carver, Ronald P., & Darby, C. A. (1972). Analysis of the chunked reading test and reading comprehension. *Journal of Literacy Research*, *5*(4), 282–296. https://doi.org/10.1080/10862967209547064

Checa, D., & Bustillo, A. (2020). A review of immersive virtual reality serious games to enhance learning and training. *Multimedia Tools and Applications*, *79*(9–10), 5501–5527. https://doi.org/10.1007/s11042-019-08348-9

Childre, D., Martin, H., & Beech, D. (2000). The HeartMath ® Solution. *Heart*, 297.

Cohen, J. (1968). Multiple regression as a general data-analytic system. *Psychological Bulletin*. https://doi.org/10.1037/h0026714

Custers, R., & Aarts, H. (2010). The unconscious will: How the pursuit of goals operates outside of conscious awareness. *Science*, *329*(5987), 47–50. https://doi.org/10.1126/science.1188595

Dane, E., Baer, M., Pratt, M. G., & Oldham, G. R. (2011). Rational Versus Intuitive Problem Solving: How Thinking " Off the Beaten Path" Can Stimulate Creativity. *Psychology of Aesthetics, Creativity, and the Arts*, *5*(1), 3–12. https://doi.org/10.1037/a0017698

Dewey, J., & Bento, J. (2009). Activating children's thinking skills (ACTS): The effects of an infusion approach to teaching thinking in primary schools. *British Journal of Educational Psychology*. https://doi.org/10.1348/000709908X344754

Dewey, J., (1910). *How we think*. , (pp. 1-13). Lexington, MA, US: D C Heath, vi, 228 pp.

Digital intuition. (2016). *Nature*, *529*(7587), 437. https://doi.org/10.1038/529437a

Eubanks, D. L., Murphy, S. T., & Mumford, M. D. (2010). Intuition as an influence on creative problem-solving: The effects of intuition, positive affect, and training. *Creativity Research Journal*, *22*(2), 170–184. https://doi.org/10.1080/10400419.2010.481513

Ferguson, R. B. (2013). Team GB: Using Analytics (and Intuition) To Improve Performance. *MIT Sloan Management Review*, *54*(3), 1-n/a. http://sfx.scholarsportal.info/ottawa?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%3Aabiglobal&atitle=Team+GB%3A+Using+Analytics+%28and+Intuition%29+To+Improve+Performance&title=MIT+Sloan+Management+Revi

Fernández-Pérez, V., Alonso-Galicia, P. E., María del Mar, F.-F., & Rodriguez-Ariza, L. (2014). Business social networks and academics' entrepreneurial intentions. *Industrial Management + Data Systems*, *114*(2), 292–320. https://doi.org/http://dx.doi.org/10.1108/IMDS-02-2013-0076

Gibney, E. (2016). Google AI algorithm masters ancient game of Go. *Nature*, *529*(7587), 445–446. https://doi.org/10.1038/529445a

Gigerenzer, G., & Gaissmaier, W. (2011). Heuristic decision making. *Annual Review of Psychology*, *62*, 451–482. https://doi.org/10.1146/annurev-psych-120709-145346

Gmür, M. (2003). Co-citation analysis and the search for invisible colleges: A methodological evaluation. *Scientometrics*, *57*(1), 27–57.

Gobet, F., & Chassy, P. (2008). Towards an alternative to Benner's theory of expert intuition in nursing: A discussion paper. *International Journal of Nursing Studies*, *45*(1), 129–139. https://doi.org/10.1016/j.ijnurstu.2007.01.005

Haar Horowitz, A., Cunningham, T. J., Maes, P., & Stickgold, R. (2020). Dormio: A targeted dream incubation device. *Consciousness and Cognition*, *83*, 102938. https://doi.org/10.1016/j.concog.2020.102938

Hagen-Foley, D. (2005). Forget Thinking, It's Your Heart Rhythms, Stupid! *PsycCRITIQUES*, *50*(38), 1. https://doi.org/10.1037/05194712

Hawk, T. F. (2011). Learning in Adulthood: A Comprehensive Guide. In S. Francisco (Ed.), *Academy of Management Learning & Education* (Third edit, Vol. 10, Issue 1). Jossey Bass. https://doi.org/10.5465/amle.2011.59513284

Hoffrage, U., & Marewski, J. N. (2015). Unveiling the Lady in Black: Modeling and aiding intuition. *Journal of Applied Research in Memory and Cognition*, *4*(3), 145–163. https://doi.org/10.1016/j.jarmac.2015.08.001

Iannello, P., Colombo, B., Germagnoli, S., & Antonietti, A. (2020). Enhancing intuition in problem solving through problem finding. In *Handbook of Intuition Research as Practice* (pp. 255–267). https://doi.org/10.4337/9781788979757.00029

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*(4), 1515–1529. https://doi.org/10.1007/s10639-017-9676-0

Johnson, J. G., & Raab, M. (2003). Take the first: Option-generation and resulting choices. *Organizational Behavior and Human Decision Processes*, *91*(2), 215–229. https://doi.org/10.1016/S0749-5978(03)00027-X

Kahneman, D. (2012). Thinking, fast and slow. *Choice Reviews Online*, *49*(10), 49-5972-49–5972. https://doi.org/10.5860/choice.49-5972

Kahneman, D. (2003). A Perspective on Judgment and Choice: Mapping Bounded Rationality. *American Psychologist*, *58*(9), 697–720. https://doi.org/10.1037/0003-066X.58.9.697

Kahneman, D., & Klein, G. (2009). Conditions for intuitive expertise: A failure to disagree. *American Psychologist*, *64*(6), 515–526. https://doi.org/10.1037/a0016755

Kermarrec, G., & Bossard, C. (2014). Defensive soccer players' decision making: A naturalistic study. *Journal of Cognitive Engineering and Decision Making*, *8*(2), 187–199. https://doi.org/10.1177/1555343414527968

King, L., & Clark, J. M. (2002). Intuition and the development of expertise in surgical ward and intensive care nurses. *Journal of Advanced Nursing*, *37*(4), 322–329. https://doi.org/10.1046/j.1365-2648.2002.02105.x

Klein, G., Calderwood, R., & Clinton-Cirocco, A. (2010). Rapid Decision Making on the Fire Ground: The Original Study Plus a Postscript. *Journal of Cognitive Engineering and Decision Making*, *4*(3), 186–209. https://doi.org/10.1518/155534310X12844000801203

Kolb, A., & Kolb, D. (2017). Experiential Learning Theory as a Guide for Experiential Educators in Highe...: DISCOVER for Books, Articles and Media. *A Journal for Engaged Educators*, *1*(1), 7–44. https://eds.b.ebscohost.com/eds/detail/detail?vid=6&sid=ec22dd52-08e4-405f-b976-3e6fe46322f1%40sessionmgr102&bdata=JnNpdGU9ZWRzLWxpdmU%3D#db=a9h&AN=124424435

Kolb, A. Y., & Kolb, D. A. (2005). Learning styles and learning spaces: Enhancing experiential learning in higher education. *Academy of Management Learning and Education*, *4*(2), 193–212. https://doi.org/10.5465/AMLE.2005.17268566

Krokos, E., Plaisant, C., & Varshney, A. (2019). Virtual memory palaces: immersion aids recall. *Virtual Reality*, *23*(1), 1–15. https://doi.org/10.1007/s10055-018-0346-3

Kuo, W. J., Sjöström, T., Chen, Y. P., Wang, Y. H., & Huang, C. Y. (2009). Intuition and deliberation: Two systems for strategizing in the brain. *Science*, *324*(5926), 519–522. https://doi.org/10.1126/science.1165598

Lampropoulos, G., Barkoukis, V., Burden, K., & Anastasiadis, T. (2021). 360-degree video in education: An overview and a comparative social media data analysis of the last decade. *Smart Learning Environments*, *8*(1). https://doi.org/10.1186/s40561-021-00165-8

Leach, S., & Weick, M. (2018). Can People Judge the Veracity of Their Intuitions? *Social Psychological and Personality Science*, *9*(1), 40–49. https://doi.org/10.1177/1948550617706732

Levitt, S. D. (2021). Heads or Tails: The Impact of a Coin Toss on Major Life Decisions and Subsequent Happiness. *Review of Economic Studies*, *88*(1), 378–405. https://doi.org/10.1093/restud/rdaa016

Lufityanto, G., Donkin, C., & Pearson, J. (2016). Measuring intuition: Nonconscious emotional information boosts decision accuracy and confidence. *Psychological Science*, *27*(5), 622–634. https://doi.org/10.1177/0956797616629403

Lurquin, J. H., & Miyake, A. (2017). Challenges to ego-depletion research go beyond the replication crisis: A need for tackling the conceptual crisis. *Frontiers in Psychology*, *8*(APR), 568. https://doi.org/10.3389/fpsyg.2017.00568

Matthews, D. (2018). Virtual-reality applications give science a new dimension toolbox. *Nature*, *557*(7703), 127–128. https://doi.org/10.1038/d41586-018-04997-2

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers and Education*, *70*, 29–40. https://doi.org/10.1016/j.compedu.2013.07.033

Micklewright, D., Kegerreis, S., Raglin, J., & Hettinga, F. (2017). Will the Conscious–Subconscious Pacing Quagmire Help Elucidate the Mechanisms of Self-Paced Exercise? New Opportunities in Dual Process Theory and Process Tracing Methods. *Sports Medicine*, *47*(7), 1231–1239. https://doi.org/10.1007/s40279-016-0642-6

Mikels, J. A., Maglio, S. J., Reed, A. E., & Kaplowitz, L. J. (2011). Should I Go With My Gut? Investigating the Benefits of Emotion-Focused Decision Making. *Emotion*, *11*(4), 743–753. https://doi.org/10.1037/a0023986

Mousavi, S., & Gigerenzer, G. (2014). Risk, uncertainty, and heuristics. *Journal of Business Research*, *67*(8), 1671–1678. https://doi.org/10.1016/j.jbusres.2014.02.013

Myers, D. G. (2007). The powers and perils of intuition. In *Tall Tales about the Mind and Brain: Separating Fact from Fiction*. Oxford University Press.

OECD. (2014, April 1). Are 15-year-olds good at solving problems? *OECD Education and Skills Today*. https://oecdedutoday.com/are-15-year-olds-good-at-solving-problems/

OECD. (2019a). PISA 2018 insights and interpretations. In *OECD Publishing*. OECD Publishing.

OECD. (2019b). Tools and Ethics for Applied Behavioural Insights: The BASIC Toolkit. In *OECDpublishing*. https://doi.org/10.1787/9ea76a8f-en

OECD. (2021). *OECD Skills Outlook 2021: Learning for Life*. OECD Publishing.

Okoli, J., Watt, J., Weller, G., & Wong, W. B. L. (2016). The role of expertise in dynamic risk assessment: A reflection of the problem-solving strategies used by experienced fireground commanders. *Risk Management*, *18*(1), 4–25. https://doi.org/10.1057/rm.2015.20

Osareh, F. (1996). Bibliometrics, citation analysis and co-citation analysis: A review of literature I. *Libri*, *46*(3), 149–158.

Owens, B. (2018). Science and technology education. *Nature*, *562*(7725), 1. https://doi.org/10.1038/d41586-018-06829-9

Paschall, M. J., Fishbein, D. H., Hubal, R. C., & Eldreth, D. (2005). Psychometric properties of virtual reality vignette performance measures: A novel approach for assessing adolescents' social competency skills. *Health Education Research*, *20*(1), 61–70. https://doi.org/10.1093/her/cyg103

Persky, S., & McBride, C. M. (2009). Immersive virtual environment technology: A promising tool for future social and behavioral genomics research and practice. *Health Communication*, *24*(8), 677–682. https://doi.org/10.1080/10410230903263982

Pilkington, A., & Teichert, T. (2006). Management of technology: Themes, concepts and relationships. *Technovation*, *26*(3), 288–299.

Pritchard, A. (1969). Statistical bibliography or bibliometrics. *Journal of Documentation*, *25*(n/a), 348.

Quirk, M. (2006). Intuition and metacognition in medical education: keys to developing expertise. In *Education for Health: Change in Learning and Practice* (Issue 2).

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers and Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Ragins, B. R. (2012). Editor's comments: Reflections on the craft of clear writing. *Academy of Management Review*, *37*(4), 493–501. https://doi.org/10.5465/amr.2012.0165

Raio, C. M., Carmel, D., Carrasco, M., & Phelps, E. A. (2012). Nonconscious fear is quickly acquired but swiftly forgotten. *Current Biology*, *22*(12), R477–R479. https://doi.org/10.1016/j.cub.2012.04.023

Reichertz, J. (2019). Abduction: The logic of discovery of grounded theory – An updated review. In *The SAGE Handbook of Current Developments in Grounded Theory* (pp. 259–281).

Rosen, M. A., Shuffler, M., & Salas, E. (2010). How Experts Make Decisions: Beyond the JDM Paradigm. *Industrial and Organizational Psychology*, *3*(4), 438–442. https://doi.org/10.1111/j.1754-9434.2010.01267.x

Sadler-Smith, E., & Shefy, E. (2004). The intuitive executive: Understanding and applying "gut feel" in decision-making. *Academy of Management Executive*, *18*(4), 76–91. https://doi.org/10.5465/AME.2004.15268692

Sætre, A. S., & Van de Ven, A. H. (2021). Generating Theory by Abduction. *Academy of Management Review*, *46*(4), 684–701. https://doi.org/10.5465/amr.2019.0233

Salas, E., Rosen, M. A., & Diaz-Granados, D. (2010). Expertise-based intuition and decision making in organizations. *Journal of Management*, *36*(4), 941–973.

Schlottmann, A., & Wilkening, F. (2012). Judgement and Decision Making in Young Children: Probability Expected Value, Belief Updating, Heuristics and Biases. In *Judgement and Decision Making as a Skill: Learning, Development, and Evolution* (pp. 55–83).

Schuster, L., & Glavas, C. (2017). Exploring the dimensions of electronic work integrated learning (eWIL). *Educational Research Review*, *21*, 55–66. https://doi.org/10.1016/j.edurev.2017.04.001

Seligman, M. E. P., & Kahana, M. (2009). Unpacking intuition: A conjecture. *Perspectives on Psychological Science*, *4*(4), 399–402. https://doi.org/10.1111/j.1745-6924.2009.01145.x

Shuell, T. J. (1986). Cognitive Conceptions of Learning. *Review of Educational Research*, *56*(4), 411–436. https://doi.org/10.3102/00346543056004411

Simon, H. A. (1987). Making Management Decisions: the Role of Intuition and Emotion. *Academy of Management Perspectives*, *1*(1), 57–64. https://doi.org/10.5465/ame.1987.4275905

Skinner, B. F. (1989). The Origins of Cognitive Thought. *American Psychologist*, *44*(1), 13–18. https://doi.org/10.1037/0003-066X.44.1.13

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. In *Frontiers Robotics AI* (Vol. 3, Issue DEC). https://doi.org/10.3389/frobt.2016.00074

Sol Rogers. (2019). Virtual Reality: THE Learning Aid Of The 21st Century. *Forbes*. https://www.forbes.com/sites/solrogers/2019/03/15/virtual-reality-the-learning-aid-of-the-21st-century/?sh=6474bfc7139b

Temple, I. G., Williams, H. G., & Bateman, N. J. (1979). A test battery to assess intrasensory and intersensory development of young children. *Perceptual and Motor Skills*, *48*(2), 643–659. https://doi.org/10.2466/pms.1979.48.2.643

Thatcher, S. M. B., & Fisher, G. (2022). From the Editors—The Nuts and Bolts of Writing a Theory Paper: A Practical Guide to Getting Started. *Academy of Management Review*, *47*(1), 1–8. https://doi.org/10.5465/amr.2021.0483

Todd, P. M., & Gigerenzer, G. (2007). Environments that make us smart: Ecological rationality. *Current Directions in Psychological Science*, *16*(3), 167–171. https://doi.org/10.1111/j.1467-8721.2007.00497.x

Torrance, E. P. (1968). A longitudinal examination of the fourth grade slump in creativity. *Gifted Child Quarterly*. https://doi.org/10.1177/001698626801200401

TORRANCE, E. P. (1972). Predictive Validity of the Torrance Tests of Creative Thinking. *The Journal of Creative Behavior*. https://doi.org/10.1002/j.2162-6057.1972.tb00936.x

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, *5*(2), 207–232. https://doi.org/10.1016/0010-0285(73)90033-9

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, *185*(4157), 1124–1131. https://doi.org/10.1126/science.185.4157.1124

van Eck, N J, & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

van Eck, Nees Jan, & Waltman, L. (2014). Visualizing bibliometric networks. In Y. Ding, R. Rousseau, & D. Wolfram (Eds.), *Measuring Scholarly Impact: Methods And Practice* (pp. 285–320). Springer.

van Eck, Nees Jan, & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics*, *111*(2), 1053–1070. https://doi.org/10.1007/s11192-017-2300-7

van Leeuwen, T. (2004). Descriptive versus evaluative bibliometrics. In *Handbook Of Quantitative Science And Technology Research* (pp. 373–388). Springer.

von Bastian, C. C., Belleville, S., Udale, R. C., Reinhartz, A., Essounni, M., & Strobach, T. (2022). Mechanisms underlying training-induced cognitive change. *Nature Reviews Psychology*, *1*(1), 30–41. https://doi.org/10.1038/s44159-021-00001-3

Waltman, L., van Eck, N. J., & Noyons, E. C. M. (2010). A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics*, *4*(4), 629–635. https://doi.org/10.1016/j.joi.2010.07.002

Wang, W., & Liu, X. (2013). The multi-attribute decision making method based on interval-valued intuitionistic fuzzy Einstein hybrid weighted geometric operator. *Computers and Mathematics with Applications*. https://doi.org/10.1016/j.camwa.2013.07.020

Wang, Y., Highhouse, S., Lake, C. J., Petersen, N. L., & Rada, T. B. (2017). Meta-analytic investigations of the relation between intuition and analysis. *Journal of Behavioral Decision Making*, *30*(1), 15–25. https://doi.org/10.1002/bdm.1903

Waroquier, L., Marchiori, D., Klein, O., & Cleeremans, A. (2010). Is It Better to Think Unconsciously or to Trust Your First Impression? A Reassessment of Unconscious Thought Theory. *Social Psychological and Personality Science*, *1*(2), 111–118. https://doi.org/10.1177/1948550609356597

Wassertheil, S., & Cohen, J. (1970). Statistical Power Analysis for the Behavioral Sciences. *Biometrics*. https://doi.org/10.2307/2529115

Fostering social and personal competencies in higher education: The ETH Competence Framework case

Barbara La Cara[1]

Strategic Initiatives (SI), Rector's Staff, ETH Zurich, Auf der Mauer 17, 8092 Zurich, Switzerland

Michèle Gemünden[2]

Educational Development and Technology (LET), ETH Zurich, Haldenbachstrasse 44, 8092 Zurich, Switzerland

Barbara Koch-Kiennast[3]

Student Services (StS), ETH Zurich, Rämistrasse 101, 8092 Zurich, Switzerland

Abstract

We describe the implementation of a competence framework comprising social and personal competencies and traditional subject- and method-specific competencies at ETH Zurich. We use mixed data to document the university's need for the framework. We find the incorporation of different perspectives about competencies pivotal for developing the framework, while joint information-sharing and competence-building enable the implementation of the framework within the university's services and educational offers. Our paper contributes to the debate in higher education on why and how universities change to prepare future-ready graduates. First, it elucidates the competencies becoming increasingly crucial for future graduates and how to conceptualise them. Second, it leverages examples showing how to promote a holistic set of competencies within the university, including the student support service, among more traditional implementation levels like degree programmes or courses.

Introduction

The world is becoming increasingly globalised, developing at a dynamic pace. To understand and interact with it, individuals must master changing technologies and process an increasing amount of information. At the same time, they face the challenge of balancing economic growth with environmental sustainability, prosperity and social equity as members of society. Literature in the future of work (e.g., National Research Council, 2012; OECD, 2013; WEF, 2020) outlines the main drivers for reconsidering future graduates' skills. For example, smart machines and systems are bringing automation into the workplace, nudging humans out of repetitive tasks, and leading to higher needs for critical thinking. A more globally connected world has created the need for intercultural skills (OECD, 2013). As society and economies rely on a competent workforce, higher education (HE) institutions are called to provide social and personal competencies, in addition to subject- and method-specific competencies (Sauter, 2018), by structuring their curricula to ensure that graduates are imparted with relevant competencies to meet the labour market (Okolie et al., 2019; Noah and Aziz, 2020) and needs

[1] barbara.lacara@sl.ethz.ch
[2] michele.gemuenden@let.ethz.ch
[3] barbara.koch@sts.ethz.ch

of society (Cimatti, 2016). Since social and personal competencies can be developed in one context and transferred to others (OECD, 2013), these transferable competencies are of paramount importance. They facilitate the application of the subject- and method-specific knowledge (Kantrowitz, 2005), enhance employability, job satisfaction (Brall, 2009; Abelha et al., 2020), individual contribution to society (OECD, 2005; Cimatti, 2016) and the resolution of real-world problems.

Literature in HE provides examples of curriculum revisions to incorporate transferable competencies (e.g., Hagman et al., 2003; Wieser et al., 2020). These studies describe reasons for curriculum revisions like considerations of employability and the need to support students' studies and display how degree programmes identify competence gaps in their curricula. Yet, they remain silent about the motivations and processes prompting universities to identify and conceptualise new competence frameworks, intended as structures defining and describing a set of competencies (Voogt & Roblin, 2012), for revising their entire educational offer. Therefore, our first research question is: *what motivates HE institutions to identify and develop competence frameworks to define the competencies that are becoming increasingly important for future graduates?* We answer this question building upon the case of the ETH Competence Framework, developed by ETH Zurich (in short ETH) as part of the ETH Talent initiative[4] to define the competencies becoming increasingly relevant for its graduates.

Fostering transferable competencies has benefits not only for a university's graduates, but also for its current students and lecturers. Students maximise their learning gains when they experience relevant competencies in the degree programme (Hansmann et al., 2019) or lecturers explicitly encourage competence development (Ngang et al., 2015). However, for benefits to happen, the fostering of transferable competencies must not be separated from the subject- and method-specific competencies (Leckley & McGuigan,1997). Learning environments that activate students connect theory and practice. For example, project-based learning and real-world examples deepen learning and simultaneously allow the development of transferable competencies (Sá & Serpa, 2018; Nägele & Stalder 2017). Therefore, integrating transferable competencies into subject-specific courses benefits conceptual knowledge development in the discipline.

Furthermore, since students also gain knowledge and skills outside the classroom, universities should consider synergies between curricula, services, and extra-curricular offers when integrating new competencies. Thus, a comprehensive competence framework at the university level would help universities prepare graduates who can match societal, environmental, and economic changes (OECD, 2013). Our paper takes a university perspective beyond the dimensions of the course or the degree programme and also considers the dimension of students' support. Therefore, our second and practical question is: *how do HE institutions promote transferable competencies?* We draw upon the implementation of the ETH Competence Framework into ETH's existing educational offers and services to answer this second question.

[4] The ETH Talent initiative was initiated in 2018 as a strategic initiative of the Rector to define and foster the competencies necessary to prepare future-ready graduates. The first author has led and developed the ETH Talent initiative since 2018 and is responsible for the overall strategy of the initiative and the development of myPath. She contributed to conceiving, designing, and writing the manuscript, including data gathering and analysis. The third author served as an advisor to the initiative from 2019 to 2022. Since 2022, the second and third authors have joined the initiative's team to implement measures in the student support service and teaching support areas. All the authors contributed to the revisioning of the manuscript. More information about the initiative can be found at https://ethz.ch/en/the-eth-zurich/organisation/executive-board/rector/eth-talent-projekt.html

A three-phase adoption of the ETH Competence Framework

Need assessment (2018)

The second half of the 2010s marked a trend in the Graduate Survey[5] responses for ETH graduates. When asked to compare their employers' competence requirements to the competencies gained from HE, graduates who finished their studies between 2010 and 2016 reported feeling over-prepared in some subject- and method-specific competencies (e.g., theoretical knowledge, analytical competencies, problem-solving). Yet, the same graduates pointed out deficiencies in transferable competencies. For example, master graduates' responses (N=998) showed, on average, a lower preparation in the ability to clarify one's point of view, teamwork, and in taking responsibility at work than the preparation requested in their jobs. Doctoral graduates' responses (N=415) displayed a similar over-preparation in subject- and method-specific competencies and self-management while suggesting competence deficiencies in time management, negotiation, and teamwork. Consistent with the other graduate groups, the bachelor graduates (N=1,045), who were asked to assess only the preparation they received from the degree programmes, reported feeling less prepared in transferable competencies like negotiation and communication of own achievements. Our first research question is partially answered by the realisation that ETH gained from these results, which motivated the university to analyse its degree programmes to uncover potential competence gaps in the existing curricular offer in September 2018. We used the qualification profiles of these programmes to map the competencies fostered at the bachelor's and master's levels.

The qualification profile is a chapter of the diploma supplement describing the knowledge and skills that graduates are assumed to have mastered at the end of their studies and reflects the competencies that a degree programme intends to foster. We analysed the bachelor’s programmes to better understand competence development across educational levels, as these programmes lay the foundations for higher educational levels. The analysis was not possible at the doctoral programmes' level as they do not have any qualification profiles. We combined inductive and deductive qualitative coding approaches (Miles et al., 2018) to detect which competencies were mentioned in the qualification profiles of sixty-nine degree programmes (28 bachelor's and 41 master's programmes).

Relying on a list of competencies derived from a summary of the latest competence frameworks for HE[6], we used the software NVivo to assign text excerpts to codes (deductive approach) and to identify open codes to allow new competencies to emerge (inductive approach). As a proxy for competence gaps in the educational offer, the less frequently a competency appeared in all the degree programmes, the less the competency was considered as fostered in the programmes, indicating higher competence needs for graduates concerning the specific competency. The results confirmed the feedback received from the graduates in the Graduate Survey. Indeed, competencies like subject-specific concepts and techniques, analytical competencies, and problem-solving were the most fostered competencies at ETH as they appeared in more than half of degree programmes, while negotiation, self-presentation, social influence, customer orientation, leadership and responsibilities, and integrity and work ethics were among the least mentioned competencies in the qualification profiles (mentioned

[5] The Graduate Survey (EHA), administrated by the Swiss Federal Statistical Office, focuses on the employment and education situation of graduates of higher education institutions one and five years after graduation. For the need assessment phase, we considered survey responses at one year after graduation. Survey results are accessible to the ETH Executive Board’s staff members and to responsible persons for the degree programmes. More information about the survey can be found at https://www.bfs.admin.ch.

[6] P21 Framework for 21st Century Learning (www.P21.org), the VITAE’s Researcher Development Framework (www.vitae.ac.uk), OECD’s Definition and Selection of Competencies Project (www.oecd.org), OECD’s Competence Framework (https://www.oecd.org/careers/competency_framework_en.pdf), the Technical University of Munich (TUM)’s Competence Framework (www.prlehre.tum.de), and the Tuning Project (http://www.unideusto.org/tuning), to name a few.

in less than a third of degree programmes). Figure 1 shows the competencies distribution across the sixty-nine programmes analysed.

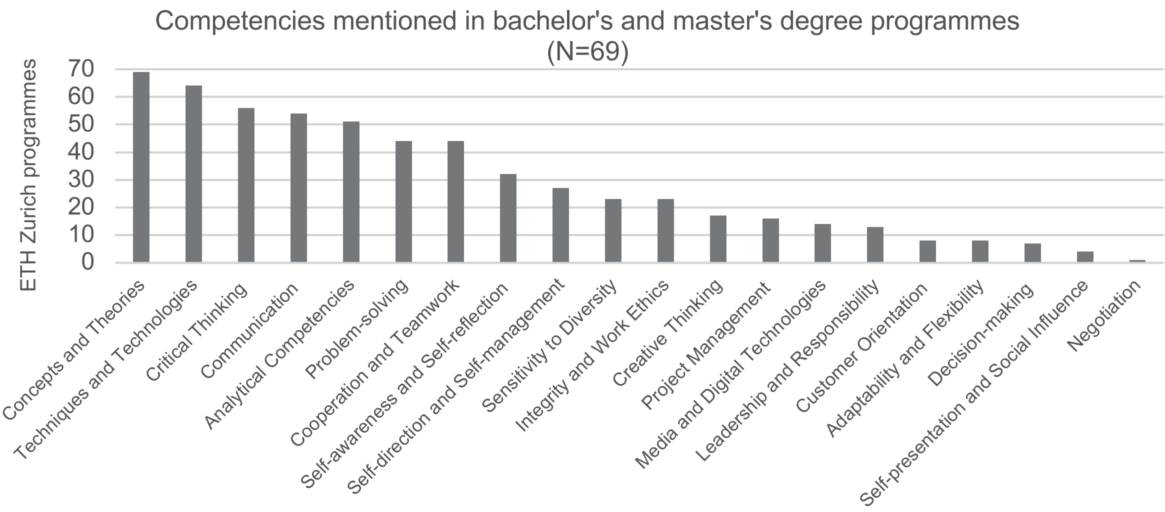

Figure 1: Competence distribution across degree programmes.

Since competence development is also relevant for employers (Deloitte, 2015) and competence requirements change over time, we complemented the need assessment phase with exploratory interviews with Swiss-based employers in October 2018. Interview questions concerned the main competence deficiencies of ETH graduates when applying for jobs, competencies becoming more relevant in the future, and employers' expectations for competence development at ETH. We deployed a mixed, intensity, and convenience sampling strategy (Flick, 2013) to select a sample of representatives from industry and academia. The final sample consisted of twenty-two organisations spanning eight economic sectors[7] and employing ETH graduates from all educational backgrounds. We interviewed each organisation's profiler, recruiter or line manager (or full professor in the case of education). The results showed that subject-specific competencies, self-awareness, and self-direction were considered relevant for entry-level employment in all sectors, followed by communication and prior experience of leadership in extra-curricular contexts, which were mentioned by three quarters of the sample. For the education sector, we considered entry-level requirements for junior researcher positions.

Employers also revealed how these transferable competencies were difficult to assess in the job application process as graduates tended not to be aware of their holistic potential and limited themselves to promoting personal achievements in the educational background area rather than discussing their interests and work experience with peers, and their potential contribution to the new job, leading to more extended job assessment periods. Lastly, more than 62% of the sample projected that, within the coming five years, personal (e.g., adaptability and flexibility, and creative thinking related to solving complex problems) and social competencies (sensitivity to diversity, customer orientation, communication, teamwork, and leadership) would become the most in-demand competencies in the future's professional world, adding to the competence needs already identified through the analysis of the

[7] The interviewees were from the following economic sectors classified according to the NOGA 2008 General Classification of Economic Activities (NOGA 2008): manufacturing; electricity, gas, steam and air conditioning supply; transportation and storage; information and communication; financial and insurance activities; professional, scientific and technical activities (e.g., management consultancy, architectural and engineering activities); education; and human health and social work activities.

qualification profiles and graduates' responses. Altogether, respondents expressed the wish for HE institutions like ETH to provide students room to experience a holistic set of competencies early on in their studies and in extra-curricular activities. To summarise, we find that incorporating the feedback from graduates, the overview of competencies to be fostered in degree programmes by lecturers, and the results of the interviews with the employers allowed ETH to identify the competencies becoming increasingly important for future graduates, answering our first research question.

Development (2019-2020)

The ETH Competence Framework[8] lists the competencies that ETH aims to foster to ensure the best job, regardless of an academic or non-academic career, and civic engagement opportunities for its graduates while guiding and inspiring teaching at ETH. Its development started alongside the need assessment phase and included two editorial rounds, each supported by feedback from internal stakeholders[9] to incorporate further needs and opinions. The first editorial efforts concerned the compilation of the first university's framework that placed subject-specific competencies at its core and identified three complementary competence domains (method-specific, social, and personal competencies)[10] to support the assimilation and deployment of subject-specific competencies (Rothe & Hinnerichs, 2005). Each competence domain included two to seven competencies for a total of twenty, derived from the integrated results from the need assessment phase.

In the second editorial round, we described the expected knowledge, skills, and attitudes outcomes for each competency following the KSA approach (Child & Shaw, 2020; OECD, 2005; Anderson et al., 2013). The newly formulated competencies' descriptors have the advantage of using a language that employers adopt in job advertisements and with which graduates are confronted when applying for jobs. Similarly, KSA-formulated descriptors support lecturers when writing the learning objectives of their courses, designing the course's content, and identifying the competencies fostered in the degree programmes. Figure 2 shows an overview of the ETH Competence Framework. This section answers research question 1, by showing how ETH moved from identifying to defining the competencies to foster.

[8] The ETH Competence Framework is available at www.ethz.ch/comp-teachingstaff

[9] Stakeholders included the Executive Board, members of the *Rektoratsrunde* (i.e., an informal body consisting of the Rector, members of the Rector's Staff, Heads of the administrative departments within the Rectorate, Corporate Communications, and the President's Office), education specialists, lecturers holding expertise in education (learning, employability, and work psychology), and members of the initiative's Advisory Board, which includes students, lecturers, educational developers and specialists, career and student coaches, and a coordinator of studies.

[10] Subject-specific competencies refer to knowledge of theories, concepts, and techniques and their application to specific disciplines; method-specific competencies concern the knowledge and application of methods to understand and operate in any context; social competencies are those competencies applied in the interaction with others; and personal competencies concern self-management in the context of own work.

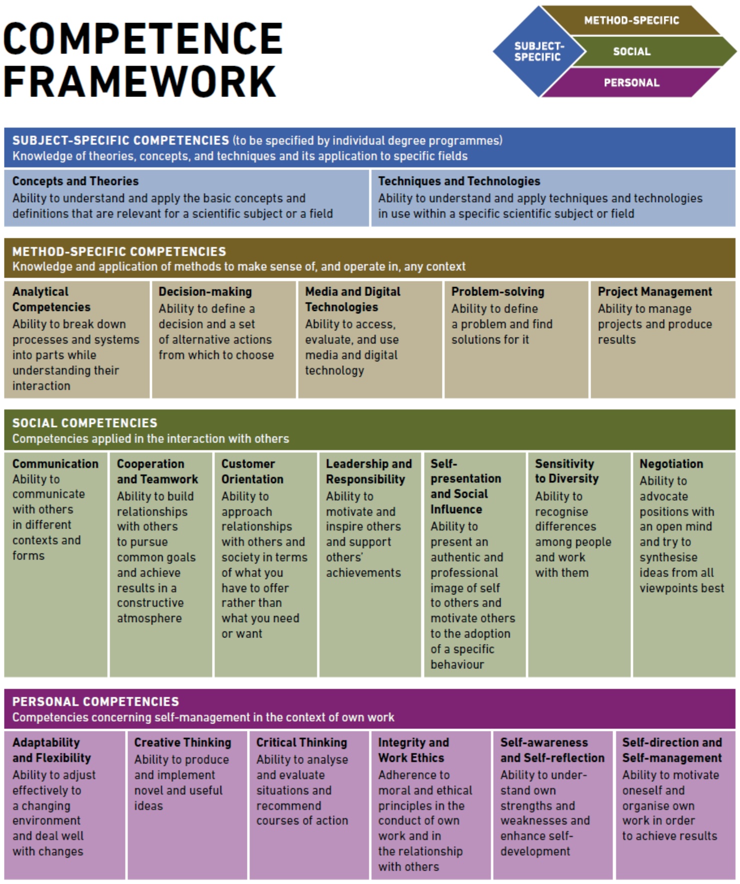

Figure 2: The ETH Competence Framework.

Implementation (2021 to date)

To answer research question 2, we observed how ETH introduced the framework into the university's operations gradually as of mid of 2021 after having compiled the final framework. The implementation phase is still ongoing and involves a mix of strategic and operational measures. While strategic measures (e.g., policy development) aim to create a sense of urgency for changing the educational offer within the university and build consensus on change (Kotter, 2012), operational measures aim to enable change in day-to-day activities (Adler & Borys, 1996).

Specifically, at a strategic level, in July 2021, the university's Executive Board formulated the policy for promoting a holistic set of competencies for future-ready graduates. The policy was later shared with the degree programmes[11]. For the first time, the degree programmes were called to integrate the fostering of transferable competencies alongside the more traditional subject-specific competencies into their curricula. The selection of the specific competencies within these competence domains was left to the autonomy and specificity of the degree programmes. In parallel, two websites, one directed to lecturers and teaching support personnel[12] and the another to students[13], were created to share the policy and underlying motivation to foster a holistic set of competencies. For example, to share the motivation, testimonials of the university's employees, Rector and graduates about the benefits of a holistic set of competencies for learners complemented a more descriptive presentation of the framework. Similarly, to motivate the university's members to use the framework, these

[11] Conference of the Directors of Studies, October 2021.
[12] www.ethz.ch/comp-teachingstaff
[13] www.ethz.ch/competencies-for-students

websites shared information on how to use it to support teaching or the students' studies and learning experience.

The second set of implementation actions aims to guide the university's members in adopting the framework in daily activities. We found that ETH is promoting transferable competencies on three dimensions: degree programmes; course teaching and administration, and student support. Table 1 provides an overview of the implementation measures.

Measures	Degree programmes	Courses	Student support
Policy	– Website for lecturers	– Website for lecturers	– Website for students
Educational offers	– Curriculum mapping tool – Past revisions catalogue – Ongoing revisions pitches – Graduates survey	– Teaching examples catalogue – Course catalogue – Course evaluation	– Educational offer catalogue
Services	– Counselling and coach-ing	– Counselling and coaching – Workshops on teaching	– Information events – Counselling and coaching

Table 1: Overview of the implementation measures.

The degree-programme dimension

At the degree programme level, these measures aim to support academic departments to identify competencies fostered in their curricula, exchange with other programmes on curriculum revisions, and receive competence-oriented feedback from graduates on their programmes. A curriculum mapping tool is under development. It will support degree programmes in tracking competence development throughout the curriculum, allowing users to manually link competence development to individual courses and visualise the fostered competencies in the degree programme. Competence-oriented mapping efforts are not new at ETH (e.g., Jödicke et al., 2016; Wieser et al., 2020).

To develop the curriculum of the Bachelor of Human Medicine, LOOOP[14], a mapping tool from Charité Berlin was used to map learning objectives (Weissmann et al., 2020). The new mapping tool will support degree programmes in tracking the fostering of transferable competencies throughout the curricula and can help to evaluate the alignment between the programme's intended learning outcomes stated in the qualification profile and the courses' content across academic semesters. Thus, the tool is especially useful for newly developed curricula and those under revision. In the future, older degree programmes could potentially use it to identify potential needs for change and draft a qualification profile to initiate a curriculum revision[15]. Moreover, degree programmes can exchange on ongoing and past curriculum revision projects at the Conference of the Directors of Studies. Invited directors of studies or curriculum revisions teams share their insights into the revisions, describing their motivation for the change, their approach, and their learnings, ultimately promoting a discussion on curriculum revisions among degree programmes. Past curriculum revision projects are also available for consultation on the Educational Development and Technology (LET) webpage[16].

Furthermore, from mid 2023, all degree programmes will also benefit from more competence-based feedback on their offers from ETH graduates, thanks to the integration of survey

[14] Learning Opportunities, Objectives and Outcomes Platform, https://looop.charite.de/
[15] https://ethz.ch/content/dam/ethz/common/docs/weisungssammlung/files-de/curriculumsentwicklung-rechtsetzung-lehre.pdf
[16] https://u.ethz.ch/k1gil

questions in the Graduates Survey administrated by the Swiss Federal Statistical Office[17] to cover the competencies described in the ETH Competence Framework. Degree programmes could use the survey to monitor possible long-term effects of curriculum revisions or to anticipate future trends in competence requirements or mismatches with their educational offers. Lastly, LET[18] has extended the support for degree programmes in curriculum development topics and clarify misunderstandings about the framework and its implementation at the degree programme level.

The course teaching and administration dimension

Gaining an overview of the competencies fostered at the degree programme level has implications for teaching at the course level. For this reason, ETH has planned different measures to support lecturers in using competence-oriented language when promoting their course's content to students, structuring their courses from scratch, revising courses, or even finding inspiration from peers about new ways of fostering competencies. For example, since 2021, the ETH Course Catalogue[19] includes a feature to signal the competencies explicitly promoted in a course, and students are better aware of what to expect to learn from the courses thanks to the information contained in the Course Catalogue. The lecturers could select the competencies during the revision phase for curricular activities of the coming academic semester by indicating on the teaching application eDoz[20] the competencies that they explicitly fostered in their courses and to what extent these were part of a formal assessment (i.e., assessed competencies) or fostered through ungraded activities like exercises, course design factors, or feedback sessions (i.e., fostered competencies).The competencies selection will become compulsory in autumn 2023.
Competence View[21] (launched in 2020) is a collection of good practices where lecturers can find inspiration for integrating transferable competencies into courses. Currently, it hosts a collection of twenty-two courses described in various formats, ranging from cookbooks to interview transcripts. Figure 3 displays Competence View.

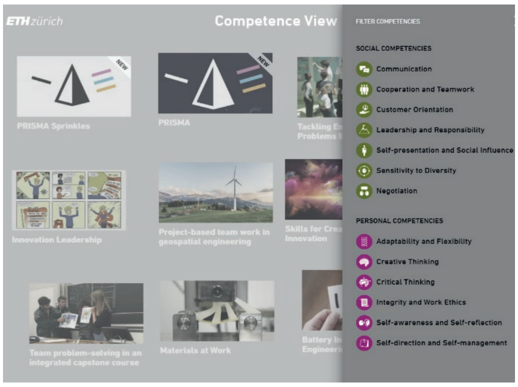

Figure 3: Competence View.

[17] The modifications of the Graduate Survey consisted in the creation of additional questions in the ETH-specific section H of the survey and coding of questions administrated to all higher education graduates in Switzerland (i.e., section D of the survey). These questions were formulated using the ETH Competence Framework's descriptors. Overall, responses to these survey items will concern the competencies levels that graduates declare to have gained from the programme attended and the competencies requirements of these graduates' employers. The results from the Graduate Survey are available on ETHIS, which is the ETH Zurich web portal for personalised access to date and evaluations of studies processed by the Institutional Research administrative department. At the degree programme level, Head, Deputy Head, Controller, Coordinators, Educational Developers, and Secretaries hold access rights to the Graduates Survey reports on this portal. The first feedback on transferable competencies will come from the cohort of students who graduated in 2021.

[18] https://ethz.ch/en/the-eth-zurich/education/educational-development/curriculum-development.html

[19] The Course Catalogue is a publication listing the range of courses available per academic semester.

[20] eDoz is an academic application that supports the lecturers at ETH Zurich with the administrative tasks connected with their teaching.

[21] Competence View is a website developed by LET, in collaboration with the ETH Talent Lead and the network of Educational Developers at ETH. More information can be found at https://www.competenceview.ethz.ch/

LET plans to offer a teaching lab to support lecturers in fostering transferable competencies from autumn 2023. An open, self-paced online course will provide lecturers with concepts of transferable competencies and how their development can be fostered in various teaching formats. Participants will be able to identify and reflect on transferable competencies fostered in their courses. An optional follow-workshop will offer the opportunity to dive deeper by explicitly planning the integration of transferable competencies into a course and exchanging and reflecting on experiences with other lecturers.

Lastly, further work is needed to enable lecturers to receive timely feedback from students on the competencies they foster in the courses.

The student support dimension

Finally, a set of measures was developed for student support. The measures aim to promote the use of the framework as a language by integrating the promotion of transferable competencies in the existing onboarding and new information events, services, and software applications for educational offers.

For example, in 2021, the university's Student Services administrative department (StS) presented the framework to incoming bachelor's students at the Prestudy Event[22]. This yearly event series is offered to students about to start their bachelor's programmes at ETH and provides information, orientation and networking to help students transitioning into HE. At these onboarding events, a game for the students, touching upon anecdotes from a day in a student's life (e.g., creating a study plan, getting involved in a study association), complemented a more general presentation of the ETH Competence Framework made on slides. The game consisted of connecting sentences to competencies. The solutions to the game were linked to a website with information about the competence framework. With a similar idea of sharing a competence-oriented language with students arriving at ETH, a new event, the Check-in Event[23], took place in 2022 to onboard master's students who had not yet studied at ETH and introduce them to the new academic culture. At this online onboarding event, students could learn about the framework and motivation for developing a holistic set of competencies and receive practical information on how to search for courses or extra-curricular activities. A similar event exists already for doctoral students at the start of their programmes[24] and is offered by the Doctoral Administration. Doctoral students who have just joined ETH can learn about the framework and discover how to use its competencies to search for ETH's curricular and extra-curricular offers. Specifically, this search is facilitated by the introduction of myPath[25], a new catalogue to allow ETH students to search for extra-curricular activities and services.

The catalogue gathers information about extra-curricular educational offers from different ETH Zurich organisers. A search engine and filters, including a filter by competencies, enable the search of the extra-curricular offer that can support students develop competencies they need to thrive in their studies and student lives at the university. Each activity or service is labelled with the competencies it promotes and presents further details concerning, for example, the learning objectives, the logistics, and the enrolment procedure. A new version is under development to enable students to enrol to activities directly on myPath, receive suggestions of educational offers (including the curricular offer) based on their interests and profile, and keep track of their engagement in competence development activities thanks to a documentation feature. The new catalogue will be released at the end of 2023. Figure 4 provides an overview of the current myPath.

22 https://ethz.ch/en/studies/bachelor/beginning-your-studies/prestudy-events.html
23 https://ethz.ch/en/studies/master/beginning-your-studies-master/check-in-master.html
24 Orientation Event. More information can be found at https://ethz.ch/students/en/doctorate/introductory-programme/Orientation/OrientationEvent.html
25 https://mypath.ethz.ch/en/

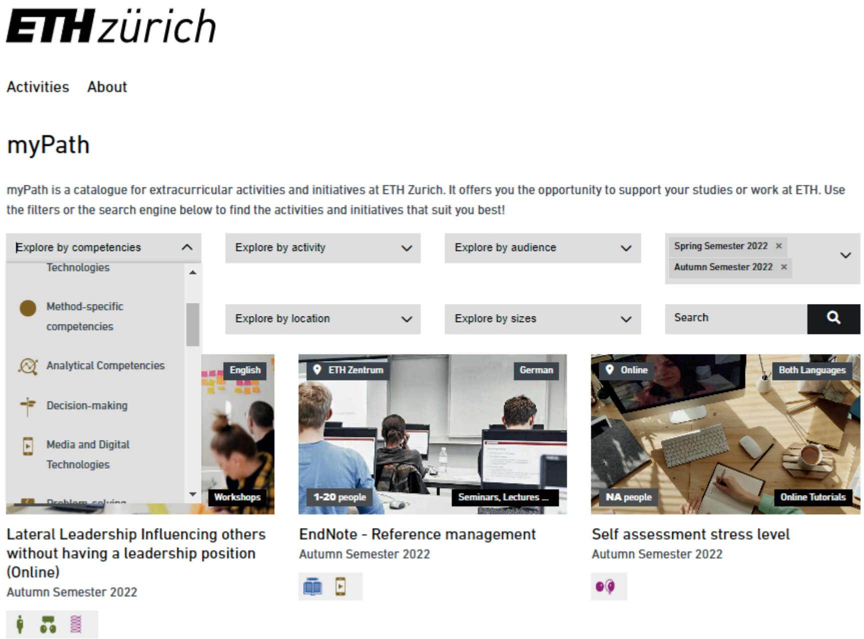

Figure 4: myPath homepage.

Furthermore, a new information event is planned to launch as a pilot at the end of 2023 to guide second-year bachelor's students, who have passed the entrance exams, to navigate ETH's educational offers. The event will allow second-year bachelor's students to reflect on themselves and become aware of their potential and competence needs by visualising the competencies already fostered in the degree programme.

Lastly, further work is needed to integrate a competence-oriented approach into the counselling and coaching service for students to guarantee tailored and in-person support for the students. In this regard, the StS Counselling & Coaching team is currently analysing the existing service and plans to train their staff in using the framework to praise the competencies of bachelor's and master's students as they arise in the counselling sessions. Praising will help the students draw a direct connection between competencies and their experience with them, ultimately leading to a deeper understanding of specific competencies and higher awareness about their potential. Despite its relevance, the offer of in-person counselling sessions for doctoral students at ETH limits itself to specific topics. For example, the university's association of scientific staff at ETH Zurich (AVETH)[26] offers counselling on academic, administrative and personal issues, and the ETH Career Center[27] provides doctoral students with counselling on career-related topics. There is a risk of overlooking the fostering of crucial transferable competencies for these students. Therefore, we see the need for further work to extend the support offered to doctoral students to guarantee a comprehensive development of transferable competencies for all ETH students.

Discussion

The previous section addressed the research questions by showing how ETH Zurich identified and defined transferable competencies (first research question) and has leveraged the ETH Competence Framework to start to foster them on three levels (degree programmes; course teaching and administration, and student support) for educating future-ready graduates (second research question) Our results extend the literature in HE in three ways. First,

[26] https://www.aveth.ethz.ch/
[27] https://ethz.ch/en/industry/industry/attract-eth-talents/career-center.html

Hansmann et al. (2019) described how graduate survey responses initiate an internal analysis of competencies fostered in degree programmes and ultimately lead to curriculum revisions. We extend this work by showing that employers' feedback on graduates' preparation and future competence requirements (Leckey & McGuigan, 1997) helps universities gain a comprehensive view of their graduates' needs. Secondly, consistent with the work by Wieser et al. (2020), we outline the need for multiple editorial rounds and stakeholder engagement in defining new competencies.

Our paper extends this work by shedding light on the stakeholders necessary to ensure feedback exchange across academic and administrative departments to seek consensus at the university level. Lastly, in describing the implementation phase of the ETH Competence Framework, we argue that synergies across students' support, extra-curricular activities, teaching support and degree programmes are pivotal to (starting to) implement measures within the university. This university perspective enriches prior research showcasing the implementation of new competencies at the degree programme (e.g., Wieser et al., 2020; Weissmann et al., 2020) or course levels (e.g., Bailey et al., 2012).

However, enacting university-wide change requires time. We estimate ETH Zurich will need five to ten years to complete the implementation stage. By then, thanks to greater awareness of competencies and more experience with developing them across disciplines, we wish to see graduates able to communicate their potential convincingly during recruiting and identify organisations matching their holistic profiles, leading to shorter unemployment duration and better placement (Brall, 2009). We know that these outcomes could be delayed in the future as we anticipate adjusting the implementation measures and timeline in the face of possible resistance from the degree programmes that could fear neglecting subject-specific competencies or raise new needs. Still, we wish to observe better research implemented with former students inspired by lecturers who were engaged in and enjoyed fostering competencies through different ways of teaching (e.g., project-based learning), ensuring that the students experienced the connection between disciplinary knowledge and transferable competencies. Lastly, we envision more graduates proactively resolving global problems (OECD, 2005) and contributing to a more cohesive society (Cimatti, 2016).

To conclude, this paper describes how ETH Zurich identified, conceptualised, and started to integrate the fostering of transferable competencies for educating future graduates. We hope our lessons learned can inform future university-wide initiatives. We observed that incorporating three distinct perspectives on competence development (i.e., lecturers', students', and employers' perspectives) was pivotal to depicting a comprehensive picture of graduates' competence needs and building consensus for integrating new competencies within the university. Moreover, using the KSA approach to describe competencies enabled the ETH Talent Initiative to reach early adopters among lecturers and administrative personnel who voiced that tangible performance outcomes helped them connect abstract concepts (competencies) to concrete examples of competence application in practice (descriptors). However, incorporating different perspectives and additional editorial efforts required more time than anticipated.

We also found the combination of information-sharing and competence-building measures necessary for the implementation of the ETH Competence Framework. While information-sharing channels and events (e.g., websites, information events) helped draw attention to the ETH's policy and teaching culture, they have also encouraged university members and students to reach out to ask clarifying questions (e.g., about the framework) or suggest further requirements for implementing the framework in their daily activities (e.g., specifications for myPath or for the Course Catalogue). In this sense, linking information with concrete offers and competence-building opportunities to benefit from them has shown some positive effects on inspiring people and prompting their initial action. Lastly, we anticipate that further needs for additional (or modified) measures will arise when moving towards a university-wide implementation. However, we trust that flexibility in the implementation will help engage the university's community, uncover needs, and achieve full promotion of competence-oriented teaching.

Acknowledgement

We want to express our special thanks to Sarah M. Springman for initiating the ETH Talent initiative; Günther Dissertori, ETH Rector, for continuing the initiative and supporting it in its implementation phase; Judith Zimmermann for her invaluable guidance; the members of the ETH Talent's Steering Committee and Advisory Board, all the participants to the 2020 Teaching Retreat for the theme of Cross-disciplinary Competencies, the employers interviewed, Gudela Grote, Manu Kapur, Elsbeth Stern, Evelyne Kappel, Christin Kaiser, Martin Ghisletti, and the network of ETH Educational Developers for their comments on various versions of the ETH Competence Framework and first-hand promotion of the framework in their academic departments. We could not have imagined such a change for ETH Zurich without you. Lastly, we thank the two anonymous reviewers and the journal's editors for improving our manuscript with their feedback.

Bibliography

Abelha, M., Fernandes, S., Mesquita, D., Seabra, F. & Ferreira-Oliveira, A. T. (2020). Graduate employability and competence development in higher education—A systematic literature review using PRISMA. *Sustainability*, *12*(15), 5900.

Adler, P. S. & Borys, B. (1996). Two types of bureaucracy: Enabling and coercive. *Administrative science quarterly*, 61-89.

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R. & Wittrock, M. C. (2013). A Taxonomy for Learning, Teaching, and Assessing. *Pearson New International Edition: A Revision of Bloom's Taxonomy of Educational Objectives*, Abridged Edition. Harlow: Pearson Education Limited.

Bailey, C. P., Minderhout, V. & Loertscher, J. (2012). Learning transferable skills in large lecture halls: Implementing a POGIL approach in biochemistry. *Biochemistry and Molecular Biology Education,* 40(1), 1-7.

Brall, S. (2009). Überfachliche Kompetenzanforderungen in den Ingenieur-wissenschaften. *Eine Literaturanalyse (RWTH Aachen University) Aachen*.

Child, S. F. & Shaw, S. D. (2020). A purpose-led approach towards the development of competency frameworks. *Journal of Further and Higher Education*, *44*(8), 1143-1156.

Cimatti, B. (2016). Definition, development, assessment of soft skills and their role for the quality of organisations and enterprises. *International Journal for quality research*, *10*(1), 97.

Cohen, P. A. (1981). Student ratings of instruction and student achievement: A meta-analysis of multisection validity studies. *Review of educational Research*, *51*(3), 281-309.

Deloitte (2015). Mind the gaps. *The 2015 Deloitte Millennial survey.*

Flick, U. (2013). *The SAGE handbook of qualitative data analysis.* Thousand Oaks, California: Sage Publications.

Hagmann, J., Almekinders, C. J. M., Bukenya, C., Guevara, F. & Halemichael, A. (2003). Developing'soft skills in higher education. *PLA notes*, *48*, 21-25.

Hansmann, R., Jödicke, A., Brändle, U., Guhl, D. & Frischknecht, P. (2019). How the Bologna reform influenced learning outcomes: Analysis of perceived qualifications and professional requirements of environmental sciences graduates. *Studies in Higher Education*, *44*(6), 1004-1022.

Jödicke, A., Hansmann, R., Brändle, U., Guhl, D. & Frischknecht. P. (2016). *Umweltnaturwissenschaften: Vom Studium zum Beruf, Ergebnisse der Absolvent(inn)enbefragungen 2009 bis 2013 der Abschlussjahrgänge 2008 bis 2012 (Master und Doktorat).* Zurich: D-USYS ETH Zurich.

Kantrowitz, T. M. (2005). *Development and construct validation of a measure of soft skills performance*. Georgia Institute of Technology.

Kotter, J. P. (2012). *Leading change.* Boston (MA): Harvard business press.

Leckey, J. F. & McGuigan, M. A. (1997). Right tracks – wrong rails: The development of generic skills in higher education. *Research in Higher Education*, *38*(3), 365-378.

Miles, M. B., Huberman, A. M. & Saldaña, J. (2018). *Qualitative data analysis: A methods sourcebook*. Thousand Oaks, California: Sage Publications.

National Research Council. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. National Academies Press.

Nägele, C. & Stalder, B.E. (2017). Competence and the Need for Transferable Skills. In: Mulder, M. (eds) *Competence-based Vocational and Professional Education. Technical* *and Vocational Education and Training: Issues, Concerns and Prospects*, vol 23. Springer, Cham.

Ngang, T. K., Yie, C. S. & Shahid, S. A. M. (2015). Quality teaching: Relationship to soft skills acquisition. *Procedia-Social and Behavioral Sciences*, *191*, 1934-1937.

Noah, J. B. & Aziz, A. A. (2020). A Systematic review on soft skills development among university graduates. *EDUCATUM Journal of Social Sciences*, *6*(1), 53-68.

NOGA (2008). General Classification of Economic Activities. Accessed 19 October 2022. https://www.bfs.admin.ch/bfs/en/home/statistics/industry-services/nomenclatures/noga.assetdetail.344669.html

OECD (2005). The Definition and Selection of Key Competencies (DeSeCo). Accessed 13 September 2022. https://www.oecd.org/pisa/35070367.pdf

OECD (2013). The future of education and skills. Education 2030. Accessed 13 September 2022. https://www.oecd.org/education/2030/E2030%20Position%20Paper%20 (05.04.2018).pdf

Okolie, U. C., Nwosu, H. E. & Mlanga, S. (2019). Graduate employability: How the higher education institutions can meet the demand of the labour market. *Higher education, skills and work-based learning*.

Rothe, H. J. & Hinnerichs, L. (2004). Wissens-und Kompetenzmanagement– verhaltensbeeinflussende subjektive und organisationale Bedingungen. *Kompetenzmessung im Unternehmen Arbeitsgemeinschaft Betriebliche Weiterbildungsforschung eV (Hrsg.),* Waxmann, Münster, New York, München, Berlin, 673-759.

Sá M. J. & Serpa S. (2018). Transversal Competences: Their Importance and Learning Processes by Higher Education Students. *Education Sciences*, 8(3):126.

Sauter, W. (2018), Die Zukunft des Lernens, Gütersloh: Bartelsmann Stiftung.

Voogt, J. & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of curriculum studies,* 44(3), 299-321.

Weissmann, Y., Wolfrum, C. & Goldhahn, J. (2020). Bachelor Humanmedizin an der ETH Zürich. *Praxis,* 109(11), 853-858.

Wieser, A., Buff Keller, E. & Graf, S. (2020). Integrating transferable skills into an existing curriculum: The example of Geospatial Engineering at ETH Zurich. *ETH Learning and Teaching Journal*, *2*(S 2), 281-286.

World Economic Forum. (2020). *The future of jobs report 2020*. Accessed 13 September 2022. https://www.voced.edu.au/content/ngv%3A88417

ETH Learning and Teaching Journal | Vol 4, No 1, 2023 | https://learningteaching.ethz.ch
Issue Editors: Dr. Michèle Gemünden, Dr. Pia Scherrer, Dr. Benno Volk
Editors: Dr. Pia Scherrer, Dr. Benno Volk
Educational Development and Technology (LET) | journal@let.ethz.ch
Design: null-oder-eins visuelle gestaltungen | nitsch@null-oder-eins.ch
ISSN 2624-7992 (Online) | © ETH Zurich, July 2023