Transdisciplinary perspectives on validity: bridging the gap between design and implementation for technology-enhanced learning systems

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CONCLUSION: TRANSDISCIPLINARY PERSPECTIVES ON VALIDITY

At the outset of this dissertation, we motivated why a transdisciplinary research approach could potentially benefit the design and validation of technology-enhanced learning (TEL) solutions, highlighting its specific relevance in connection to our GEIGER cybersecurity project for SMEs. We presented our main research question: *How can transdisciplinary research inform the design and validation of technology-enhanced learning solutions?* In this concluding chapter, we will reflect on how the individual pieces of our research puzzle have helped us move towards an answer to our main research question. Additionally, we will discuss how our designed artefacts have impacted science and society, and will contemplate possibly fruitful directions for future research.

10.1 CONTRIBUTIONS

Figure 10.1, first presented in Chapter 1, visualises the research process that was followed in this dissertation. We matched the phases of the transdisciplinary research process, which informed how we could incorporate insights from different fields of research and societal stakeholders, to the phases of the engineering cycle, which informed the research methods we used to answer the research questions of the various chapters in this dissertation. We can now reflect on how the answers to sub-questions combine towards answering our main research question.

CHAPTER 2 uncovered the elements of an accessible and swift systematic review methodology. We presented the systematic review methodology SYMBALS, which combines an active learning approach in the title and abstract screening phase with a backward snowballing step to find additional literature. Using two case studies, we demonstrated the ability of SYMBALS to speed up the review process, while simultaneously managing to retrieve a significant proportion of all relevant papers. SYMBALS was used in several later chapters within this dissertation, and has been used by scientists to aid their systematic review process in fields ranging from computer science to marine policy to sports medicine. Thus, this chapter formed the first step in investigating our problem domain.

CHAPTER 3 examined the topic of SME cybersecurity measurement using a SYMBALS systematic review. We synthesised our findings into a socio-technical cybersecurity framework for SMEs, where we indicated how different cornerstones of the SME socio-technical system can be expected to interact at different levels of digital maturity. The framework developed in Chapter 3 informed the co-creation and design work we executed in later studies.

CHAPTER 4 addressed the question: How should an SME cybersecurity application be designed to motivate users? Using a collaborative design research approach, we designed an initial version of the GEIGER application. The educational content and user interface of the application were created together with users, and were also informed by the cybersecurity framework of Chapter 3 and behavioural theories. The artefact resulting from this study, a prototype educational cybersecurity application for SMEs, is central to the GEIGER product offering to this day. Through the active involvement of SME users, this study represented the initial foray into the domain of transdisciplinary research. Regarding our main research question, we can surmise from the findings of this chapter that a transdisciplinary approach to the design of TEL solutions can help to promote motivation by explicitly considering the behavioural needs of users.

CHAPTER 5 used a technical action research approach to investigate how cyber threat intelligence could be incorporated into the GEIGER application. We described in detail how threat intelligence, which in its raw form can be difficult to understand for cybersecurity experts, could be turned into actionable insights for SMEs. The threat intelligence platform that we developed together with industry partners was the first example of a technical cybersecurity pipeline that provided real-time, understandable insights to users with limited cybersecurity knowledge and resources. Through the involvement of both industry partners and SMEs, we learned that just because raw data is considered too difficult to understand for people without expert knowledge, it does not mean this raw data cannot be used to create an improved design for these people.

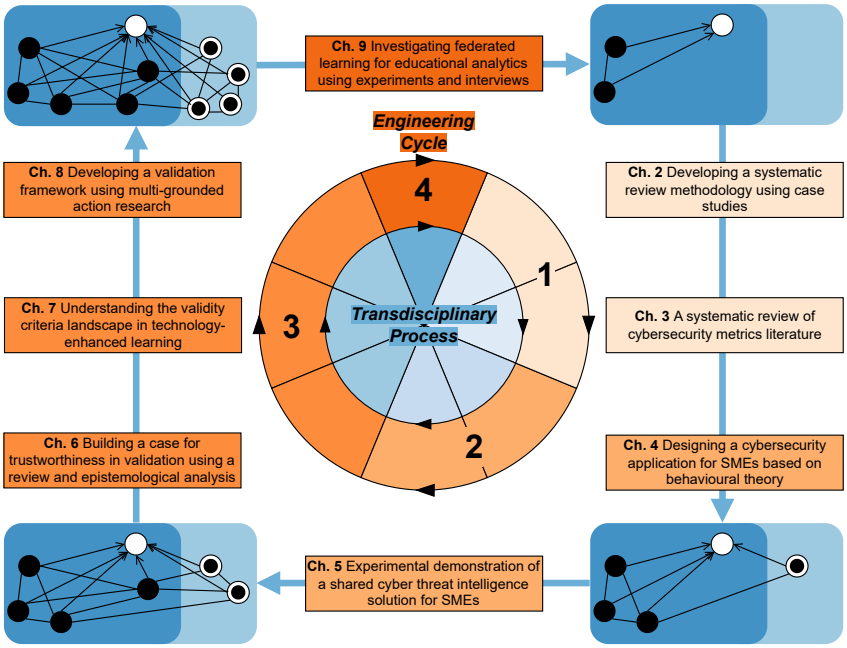

Figure 10.1: The visualisation of our research process that was first presented in Chapter 1. We combine the transdisciplinary process described by Lawrence et al. (2022) and the engineering cycle of Wieringa (2014).

CHAPTER 6 was the first chapter where our focus shifted from design to validation, and from a narrow, context-specific view used to design an educational cybersecurity application for SMEs, to a broad view used to develop a validation framework for TEL. In Chapter 6, we employed a combination of a literature review and an epistemological analysis to develop a theoretical basis

for validity considerations in learning analytics. We presented an overview of how existing validity criteria are used by researchers, which informed the design of a Learning Analytics Validation Assistant (LAVA).

CHAPTER 7 extended the work of Chapter 6 using a SYMBALS systematic review. We uncovered which validity criteria are considered in TEL research, which methods are used to gain insight into these criteria, and whether criteria are on average assessed positively or negatively. By comparing criteria definitions and usage over time, we created an overview of the validity criteria landscape, which could inform future holistic validation frameworks. In combination, Chapter 6 and Chapter 7 demonstrated how crossing disciplinary boundaries can yield a more holistic image of validity in the context of TEL.

CHAPTER 8 investigated how a holistic validation framework for TEL could be constructed. Through a multi-grounded action research approach we developed VAST, a validation framework for e-assessment technologies such as GEIGER. We additionally created a guideline to accompany our academic contribution (van Haastrecht, M. J. S. Brinkhuis, and Spruit, 2023), which is intended to help users of VAST gain an understanding of the step-by-step process underlying the framework. Whether our framework will serve as a useful validation tool for researchers and practitioners is yet to be seen, but the societal stakeholders with which we developed the framework have surely gained valuable insights concerning potential validation strategies. The input from societal stakeholders helped us to gain an understanding of the importance of clarity and flexibility in validation frameworks; understanding we would not have been able to gain without a transdisciplinary research approach.

CHAPTER 9 covered the question: How does the privacy-performance trade-off manifest itself in educational analytics? After performing technical experiments to demonstrate the potential of federated learning for educational analytics, we introduced a novel metric (FLAME) that assists policymakers in their assessment of the privacy-performance trade-off. We presented preliminary findings from a series of interviews with stakeholders, to reflect on the viability of introducing advanced machine learning techniques into educational contexts. The interviewees indicated that federated learning could serve as a stepping stone to move from experimental techniques to large-scale innovation, whereas we had initially envisioned a federated learning architecture as a replacement for central learning. This formed another reminder that a transdisciplinary research approach can not only inform the comprehensive validation of TEL innovations, but might in fact be a requirement for comprehensive validation.

10.2 IMPLICATIONS

Our transdisciplinary research approach informed the design and validation of the GEIGER solution. But can we generalise our findings beyond the GEIGER project?

We demonstrated how technical knowledge extracted from scientific literature using an innovative systematic review approach (Chapter 2, Chapter 3), can be incorporated in the design of a TEL solution in collaboration with users and industry partners (Chapter 4, Chapter 5). We argue that although the work of the first chapters focused primarily on the GEIGER use case, its findings are applicable to a large range of contexts, as exemplified by the variety of research areas in which SYMBALS has been employed.

Later chapters exercised a broader view from the outset, to inform the studies related to validation. We developed a theoretical basis for learning analytics validation (Chapter 6), before expanding on this work using a SYMBALS review to create a comprehensive overview of the TEL validity landscape (Chapter 7). We designed a comprehensive framework for e-assessment technologies (Chapter 8), and applied our theoretical validation knowledge in an evaluation study of privacy-preserving machine learning for educational analytics (Chapter 9). Although the work of these later chapters was predominantly theoretical, the accumulated knowledge was generally developed in collaboration with the societal partners of the GEIGER project. We believe that our transdisciplinary approach increased the potential of our validity theory contributions to create an impact in the wider TEL domain.

Focusing on our main research question, we can conclude that transdisciplinary research facilitates the discovery of practical barriers to successfully implementing existing TEL methods, frameworks, and artefacts. However, transdisciplinary research also opens our eyes to how we can adapt and enhance our current solutions to better cater to the needs of society. Whether it is through more adequately addressing the behavioural and pedagogic needs of users, or through more critically reflecting on and contextualising our validity evidence, building bridges between science and society introduces us to new perspectives that positively influence the design and validation of TEL solutions.

10.3 LIMITATIONS

The chapters of this dissertation each mention the limitations of their corresponding studies. Three further overarching limitations should be mentioned here. Firstly, the nature of GEIGER as a research and innovation project had as a consequence that its process was fast-paced. Practical progress was regularly swifter than that of the accompanying scientific research. The result was that although the connection between science and society was prominent within the GEIGER project, it was not always as prominent within the scientific stud-

ies of this dissertation. The process of collaboration with users and industry partners is primarily described in project deliverables, which may limit the clarity regarding the impact of our transdisciplinary approach within this dissertation.

Secondly, the GEIGER project took place during the COVID pandemic. The project was luckily able to move forward, but with the limitation that much fewer personal interactions with users and project partners took place than we had planned for. We have highlighted the importance of thick descriptions of educational contexts that allow for the critical contextualisation of validity evidence. The COVID pandemic limited our ability to critically contextualise. However, we continuously sought contact with users and partners online, and used the few opportunities for in-person interaction as effectively as we could, while nonetheless remaining aware of the impact the pandemic had on our research.

Finally, one can ask to what extent we managed to achieve a satisfactory answer to our main research question. In one sense, we can argue that we have uncovered several ways in which transdisciplinary research can inform the design and validation of TEL solutions, and have thus provided an answer to our main research question. However, in another sense, certain questions remain open and we cannot rule out the possibility that there are ways in which transdisciplinary research can positively impact TEL design and validation beyond those presented here. This can be interpreted as a limitation of this dissertation, but can also be understood as a gap for future research to address.

10.4 FUTURE DIRECTIONS

Because of the nature of the engineering cycle and the transdisciplinary research process, suggestions for future directions, for a future cycle, come primarily from the studies positioned towards the end of the current cycle. Many of the questions posed in the final chapters remain open. We need to continue to adapt validation frameworks to novel technological developments, such as those producing process data in educational environments. We have to clarify existing validation frameworks and increase their flexibility, such that they become more usable for researchers and practitioners. Additionally, we should continue to unearth diverse stakeholder perspectives on our designed solutions, if we are to legitimately recognise the diversity of perspectives that exist regarding technological innovations in education. We can surmise that TEL validity theory offers a promising direction for future research endeavours.

To close, we want to reflect on two of the findings from Chapter 7, and the necessity to further investigate their implications. We observed a correlation between the research method used to assess validity criteria and the outcome - negative, positive, or mixed - of that assessment. We also exposed a potentially

problematic hierarchy in validity criteria, where certain criteria receive a much higher priority than others. If our validation strategies are misguided, our innovations will follow this misguided path. We cannot accept such a future, and thus we will need to investigate where our validation strategies may be heading astray, such that we can correct our course. Albert Einstein once said: "Not everything that can be counted counts, and not everything that counts can be counted." Let us, as science and society, figure out what counts.