Carl von Ossietzky
Universität
Oldenburg

Fakultät II – Department für Informatik

Materializing Creative Coding Ideas

Applications and Challenges of Computational Making in Youth's Coding Education

Dissertation zur Erlangung des Grades eines
"Doktor der Ingenieurwissenschaften"

vorgelegt von
Christos Chytas

Gutachterinnen:
Prof. Dr. Ira Diethelm
Prof. Dr. Heidi Schelhowe

Ort und Tag der Disputation:
Oldenburg, 25. Februar 2021

Acknowledgments

I want to thank many people whose collaboration and support made this work possible.

First, I must thank my first advisor, Ira Diethelm, for her constant support, academic guidance, and mentorship. Ira, you have not only welcomed me in your research group, but you encouraged me to follow my scientific interests and inspired me to take on challenging problems and grow as an academic and a person.

My second advisor, Heidi Schelhowe, also deserves a huge "Thank you!" for guiding me along the journey towards completing this dissertation. Her multifaceted work with digital media in education was an inspiration since the very beginning of my work at Fab Lab Bremen and diMeB.

During my time with the DDI research group and the GINT program, I had the opportunity to work with researchers from very different backgrounds and foci who shared their knowledge and perspective with me. I want to thank all former and present colleagues from both groups, especially Nils Pancratz, Tobias Stuckenberg, Anatolij Fandrich, Wibke Duwe, Mareike Daeglau, Claudia Hildebrandt, Matthias Matzner, Anastasia Striligka, Swantje Müller, Dirk Stiefs, and Sönke Janssen. Special thanks also to Susanne Weßnigk, Claus Michelsen, and Peter Röben. They have known my research since its early beginning and contributed with constructive discussions and valuable suggestions about the research methodology.

A special thanks to all colleagues at the diMeB research group and especially Michael Lund, Nadine Dittert, Iris Bockermann, and Bernd Robben, for their invaluable support on the theoretical parts of my thesis and the organization of workshops.

In the last years, I had the opportunity to work and discuss with international researchers through research visits and attending conferences to present our work. This work has greatly benefited from conversations with (among others) Jenny Sendova, Wolfgang Slany, Michail Giannakos, Sofia Papavlasopoulou, Zacharoula Papamitsiou, Monica Divitini, John Falk, Peter Labudde, and the Fablearn Fellows folks.

This research would have been impossible without the teachers, expert designers, and especially the children and youth who participated in our workshops and critically reflected on their experiences. I further thank Eike Brahms, Maximilian Rodiek, and the student assistants of our research group who contributed to the implementation and evaluation of these workshops.

Last but not least, I want to thank my family and friends for encouraging and inspiring me over the years. Without them, it would have been impossible for me to carry out this work.

Abstract

Nowadays, coding with computers has become a form of creative expression that enables the production of useful and socially significant artifacts. As automation and 3D printers replace workers in manufacturing and construction, the ability to code and design is becoming crucial for daily life and future employment. Coding and design are still seen by many as challenging activities for expertly trained individuals. However, advances in technology have led to the development of increasingly affordable and accessible computational design and fabrication tools that have reached a wide range of users, including children and youth.

This dissertation examines applications of computational design and 3D printing in coding learning activities for youth through the lens of constructionism. It presents the design, implementation and evaluation of computational design and 3D printing workshops in formal and non-formal learning environments. In those workshops, the participants had the possibility to use computational concepts and coding practices to design and fabricate personally meaningful artifacts. The workshops were evaluated using a mixed-methods approach and refined through iterative circles of design and research. The findings suggest that the workshops' approach was favorably received by both youth and teachers and increased learning gains, enjoyment, and motivation for coding activities. Challenges and barriers to using the combination of computational design and 3D printing in the classroom are identified, and teaching and learning strategies as possible solutions are discussed.

The thesis contributes to research on coding education and human-computer interaction by providing recommendations and design principles to adequately address content and pedagogical issues of integrating 3D printing technologies and coding into STEAM learning activities, as well as an in-depth understanding of the potential role of 3D printing technology and creative coding in youth's life-worlds.

Kurzfassung

Coding mit Computern ist heute zu einer Form des kreativen Ausdrucks geworden, die die Herstellung nützlicher und gesellschaftlich bedeutsamer Artefakte ermöglicht. Coding und Design werden von vielen immer noch als herausfordernde Tätigkeiten für Expert*innen angesehen. Fortschritte in der Technologie haben jedoch zur Entwicklung immer günstigerer und zugänglicherer Tools für Computational Design und digitale Fabrikation geführt, die ein breites Spektrum von Benutzer*innen, darunter auch Kinder und Jugendliche, erreicht haben.

In dieser Dissertation werden die Anwendungen von Computational Design und 3D- Druck beim Coding in Lernaktivitäten für Jugendliche unter dem Blickwinkel des Konstruktivismus untersucht. Diese Arbeit präsentiert eine dreijährige empirische Forschung über Computational Design und 3D Druck Workshops an formalen und non-formalen Lernorten. Während der Workshops hatten die Teilnehmer*innen die Möglichkeit, grundlegende Konzepte der Informatik zu verwenden, um persönlich bedeutsame Artefakte zu entwerfen und herzustellen. Die Workshops wurden mit einem methodengemischten Ansatz evaluiert und durch iterative Design- und Forschungszyklen verfeinert. Die Ergebnisse zeigen, dass die Workshops sowohl von den Jugendlichen als auch von den Lehrkräften positiv aufgenommen wurden und den Lernzuwachs, die Freude und die Motivation für die Kodierungsaktivitäten erhöhten. Es werden Herausforderungen und Hindernisse für den Einsatz der Kombination von Computerdesign und 3D-Druck im Klassenzimmer identifiziert und entsprechende Lehr- und Lernstrategien als Lösungen diskutiert.

Die Dissertation leistet einen Beitrag zur Forschung auf dem Gebiet der Coding Education und der Mensch-Computer-Interaktion, indem sie Empfehlungen und Designprinzipien liefert, um die inhaltlichen und pädagogischen Fragen der Integration von 3D-Drucktechnologien und Coding in die MINT-Lernaktivitäten adäquat zu behandeln sowie ein vertieftes Verständnis der potenziellen Rolle der 3D- Drucktechnologie und des kreativen Coding für die Lebenswelt junger Menschen.

List of Publications

Parts of this dissertation include concepts, ideas, and findings from our published research studies. I was the lead author of the publications that this work is based on, except for two conference papers (Sendova et al., 2018; Pancratz et al., 2019). My contribution to both works was focused on digital fabrication and computational design tools in education and their potential for personal expression. Additionally, the dissertation follows the style of the original publications (including the first-person plural). The following list provides an overview of our published studies and the related chapters of the dissertation:

Chapter 4

- Chytas, C., Tsilingiris, A., & Diethelm, I. (2019). Exploring Computational Thinking Skills in 3D Printing: A Data Analysis of an Online Makerspace. In A. K. Ashmawy & S. Schreiter (Eds.), IEEE Global Engineering Education Conference, EDUCON 2019, Dubai, United Arab Emirates, April 8-11, 2019 (pp. 1173–1179). IEEE.

- Chytas, C., Diethelm, I., & Tsilingiris, A. (2018). Learning programming through design: An analysis of parametric design projects in digital fabrication labs and an online makerspace. In 2018 IEEE Global Engineering Education Conference, EDUCON 2018, Santa Cruz de Tenerife, Tenerife, Islas Canarias, Spain, April 17-20, 2018 (pp. 1978–1987). IEEE.

- Chytas, C., Diethelm, I., & Lund, M. (2017). Parametric design and digital fabrication in computer science education. In Online Proceedings of ISSEP 2017 - The 10th International Conference on Informatics in Schools (pp. 1–2).

Chapter 5

- Chytas, C., Tsilingiris, A., & Diethelm, I. (2019). Exploring Computational Thinking Skills in 3D Printing: A Data Analysis of an Online Makerspace. In A. K. Ashmawy & S. Schreiter (Eds.), IEEE Global Engineering Education Conference, EDUCON 2019, Dubai, United Arab Emirates, April 8-11, 2019 (pp. 1173–1179). IEEE.

- Pancratz, N., Fandrich, A., Chytas, C., Daeglau, M., & Diethelm, I. (2019). Blöcke, Blumen, Mikrocontroller und das Internet of Things. In A. Pasternak (Ed.), Informatik für alle (p. 295-304). Bonn: Gesellschaft für Informatik.

- Chytas, C., Diethelm, I., & Tsilingiris, A. (2018). Learning programming through design: An analysis of parametric design projects in digital fabrication labs and an online makerspace. In 2018 IEEE Global Engineering Education Conference, EDUCON 2018, Santa Cruz de Tenerife, Tenerife, Islas Canarias, Spain, April.

- Chytas, C., & Diethelm, I. (2018). Designing constructionist learning environments with computational design and digital fabrication. In D. Valentina & J. Egl˙e (Eds.), Proceedings of Constructionism 2018: Constructionism, Computational Thinking and Educational Innovation (pp. 547–553).

Chapter 6

- Chytas, C., Diethelm, I., & Tsilingiris, A. (2018). Learning programming through design: An analysis of parametric design projects in digital fabrication labs and an online makerspace. In 2018 IEEE Global Engineering Education Conference, EDUCON 2018, Santa Cruz de Tenerife, Tenerife, Islas Canarias, Spain, April.

Chapter 8

- Chytas, C., & Diethelm, I. (2018). Designing constructionist learning environments with computational design and digital fabrication. In D. Valentina & J. Egl˙e (Eds.), Proceedings of Constructionism 2018: Constructionism, Computational Thinking and Educational Innovation (pp. 547–553).

- Chytas, C., Diethelm, I., & Tsilingiris, A. (2018). Learning programming through design: An analysis of parametric design projects in digital fabrication labs and an online makerspace. In 2018 IEEE Global Engineering Education Conference, EDUCON 2018, Santa Cruz de Tenerife, Tenerife, Islas Canarias, Spain, April.

- Sendova, E., Chytas, C., Olędzka, K., Romeike, R., & Slany, W. (2018). Creating and looking at art with logo eyes. In D. Valentina & J. Egl˙e (Eds.), Proceedings of Constructionism 2018: Constructionism, Computational Thinking and Educational Innovation (pp. 855–867).

Table of Contents

List of Tables

List of Figures

List of Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
CAD	Computer-Aided Design
CNC	Computer Numerical Control
CS	Computer Science
CSE	Computer Science Education
CSG	Constructive Solid Geometry
CT	Computational Thinking
DF	Digital Fabrication
DIY	Do It Yourself
HCI	Human-Computer Interaction
K-12	Kindergarten-Twelfth Grade
NSF	National Science Foundation
PLA	Polylactic Acid
SOLO	Structure of Observed Learning Outcomes
STEAM	Science Technology Engineering Art and Mathematics
STEM	Science Technology Engineering and Mathematics
STL	Stereolithography
TEL	Technology-Enhanced Learning
URL	Uniform Resource Locator