PROMOTING MATH, SCIENCE AND TECHNOLOGY EDUCATION COLLABORATIVELY THROUGH DESIGN-BASED RESEARCH

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This article describes how it is possible to catalyze math, science and technology education through design-based research. It is a suitable tool for creative development, when we want to systematically (i) process together the most novel research information on math, science and technology and also on its teaching and learning, so that it is suitable for different target groups, (ii) develop new solutions based on research concerning a chosen development need or a challenge, (iii) educate teachers and future teachers collaboratively on using the new concept or activity in teaching and (ii) promote seamless collaboration between all the participants (e.g. teacher educators, researchers, teachers, future teachers and other specialists) and promote learning from each other. It has been observed that design-based research is a good tool also for collaboration with industry specialists and sponsors. This article gives an example of how design-based research is used in the Finnish LUMA system and in its teacher education.

1. *Introduction*

By using design-based research, it is possible to develop new solutions and pedagogical innovations on math, science and technology education, based on the newest research. Here, educational practices are renewed through systematic, flexible and iterative analysis, design and development (e.g. Wang & Hannafin, 2004) and solutions are produced to very complex challenges in authentic learning environments (e.g. McKenney & Reevesin, 2018). According to Edelson (2002), design-based research gives us three kinds of information: Information on (i) the development of the product itself, (ii) the collaborative development process and (iii) the background theory or theories used in the development. The collaborative dimension is a central part of design-based research: participants include e.g. teachers, future teachers, teacher educators, researchers, representatives from the educational administration or industry specialists. This method has successfully been in use at least since the 1990's. The term used in this paper, *design-based research* (e.g. Kelly, 2003; Juuti & Lavonen, 2006; Anderson & Shattuck, 2012), is just one example. There are also other terms such as *design experiments* (e.g. Brown, 1992; Collins, 1992), *design research* (e.g. Cobb, 2001; Edelson, 2002), *development research* (e.g. Richey & Nelson, 1996), and *educational design research* (e.g. Sandoval & Bell, 2004; Van der Akker, Kelly, Lesh & Baek, 2008, Sandoval, 2014).

With the help of design-based research, most novel research information (e.g. concerning nanotechnology or project-based learning) is processed collaboratively and in a creative way, so that it is suitable for each target group. As a result, we acquire concrete activities, materials, courses, learning environments, software or equipment for different levels (e.g. Brown & Campione, 1994; Cognition & Technology Group at Vanderbilt, 1997; Kelly, 2003) and for example relevant inquiry-based working instructions (e.g. Aksela, 2005; Aksela & Boström, 2012; Aksela & Ikävalko, 2016). In addition, design-based research can be used in promoting teachers' vocational development in teacher education (e.g. Sherin, 1998; Kelly, Lesh & Baek, 2008; Pernaa & Aksela, 2013; Vesterinen & Aksela, 2013). A new kind of a collaborative teacher education model in the LUMA ecosystem is described in chapter 2.

Design-based research differs from traditional education research on the following areas: according to (i) the role of the participants, (ii) the amount of social interaction, (iii) flexibility of the process, (iv) the characteristics of the results, (v) the research setting, (vi) the complexity of the variables and (vii) the object of research (e.g. Barab & Squire, 2004; Collins, 1999). The characteristics of a good design-based research guide its design and implementation process, and the report describes in detail (Dede, 2004; Design-Based Research Collective, 2003): (i) the correspondence of the design in the needs of practical and education policy, (ii) the intertwining of the aims of the chosen intervention and developed theories, (iii) the cyclicity of the development between design, implementation, analysis and re-design, (iv) the reliability of received results, (v) how the outcome of the development works in an authentic environment and (vi) how the received results adapt to earlier theories and practical implementations. The validity of design-based research is shown often through collaboration and iteration, and the reliability through using various references for the research and by evaluating the usefulness of the research concerning education and learning (e.g. Design-Based Research Collective, 2003; Edelson, 2002).

In practice, design-based research can be carried out in various ways, and different models are available for supporting development decisions carried out during design-based research (e.g. Sandoval, 2014). According to Edelson (2002), there are two parts that guide the process of design-based research and the decisions concerning the research: (a) theoretical problem analysis and (b) empirical problem analysis (see Figure 1). Chapter 2 presents how the Edelson model has been applied in the Finnish LUMA system (see https://www.luma.fi) and in its teacher education. In the different parts of the cyclic development process, the so called mixed methology is used in order to understand the object of development. For example, Aksela (2005) carried out a design-based research in which the aim was to develop, based on research, a computer-assisted solution in order to promote youths' higher level of thinking skills and to promote meaningful inquiry-based education. The following methods were used in the research's six empirical studies: video-recordings, naturalistic observations, group interviews, concept maps, learning diaries, students' research reports, and surveys.

2. *Design-based research as a development tool in the Finnish LUMA system*

One of the aims of the Finnish LUMA operations is to develop new solutions and pedagogical innovations in math, science and technology education and to promote them through collaborative teacher education and collaborative partners. Design-based research is used in order to support the implementation of current and future national core curricula, for example it has been used to promote inquiry-based education and formative assessment.

In the LUMA system and in its teacher education, design-based research has been carried out collaboratively and systematically e.g. in the following steps (Figure 1): (i) mapping out the needs together with the participants (empirical problem analysis: a needs analysis), (ii) mapping out new research information concerning the chosen theme, and synthesis (theoretical problem analysis), (iii) setting the aims of development together based on steps i) – ii), designing a pilot model for the object of development based on chosen aims, (v) testing the pilot model with the target group (empirical problem analysis) and refining it based on received results (cyclic model), (vi) describing the outcome of development, and reporting and (vii) spreading new openings and solutions, and offering education on them. Needs analysis can be based for example on survey or content analysis of learning materials. Usually a researcher at a university, a teacher educator or a future teacher carries out the synthesis and maps out new research information concerning the topic. In collaborative meetings, steps (i) and (ii) are gone over together, and the aims for development and the model for implementation with timetables are arranged together.

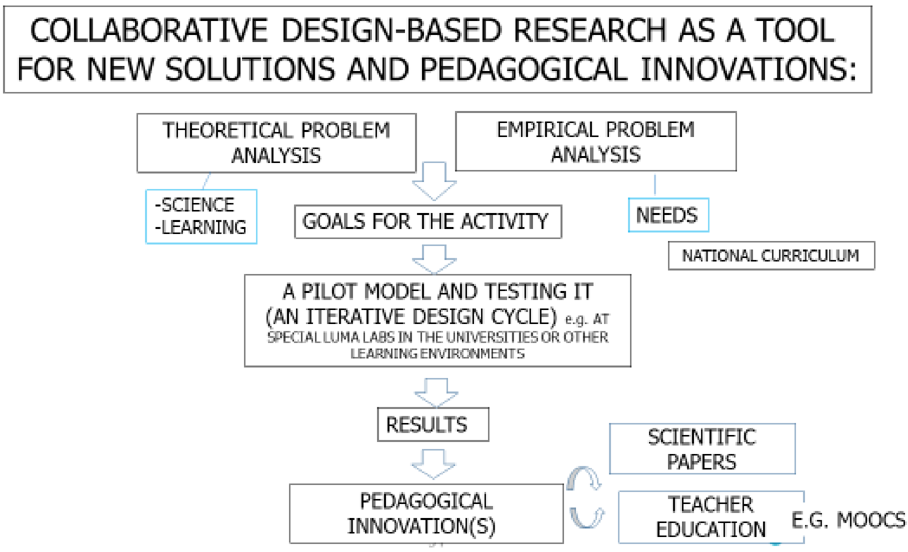

Figure 1: An example of how design-based research has been applied collaboratively in the Finnish LUMA system (see https://www.luma.fi) and in its teacher education by applying Edelson's (2002) model. As future teachers and teachers teaching in schools have participated in designing, implementing and reflecting on the results of the development process, at the same time design-based research has been acting as teacher education. These development projects are usually connected to theses, and scientific articles have been written based on the results. These acquired solutions are spread into teaching through teachers' pre-service and in-service education (e.g. through online courses (MOOCs)). An

online book (Aksela, Oikkonen & Halonen, 2018) gives a better glimpse of development projects that have been carried out.

The systematic implementation of design-based research offers a learning environment, where all participants are able to reflect and learn from one another. This forms a so-called learning society. Many have participated in the collaborative development of development projects: math and science teachers from different teaching levels, future teachers, researchers, representatives from the educational administration and teacher educators from universities and specialists from the industry. The implementation can also act as a new kind of an educational model for teachers: Teachers or future teachers can act in projects as "researching teachers", in practice they test new solutions in different stages of development with their students, they collect research data and they reflect on the results when meeting together with researchers and other participants, and they also participate in writing the report and papers concerning the research. A book on design-based research that has been produced collaboratively and that is written in Finnish, is being used in teacher education. This book contains countless examples of carrying out design-based research in education and in teacher education (Pernaa, 2013).

The development and research environments that are used can be formal, non-formal or informal learning environments. For example in one non-formal learning environment, ChemistryLab Gadolin (one of 14 LUMA Labs), new openings in the contexts of everyday chemistry, sustainable chemistry, and development and modern technology are developed together with visiting school groups (Aksela, Pernaa, Blomgren & Rautiainen, 2018). In the project *Chemistry in Society,* hands-on activities that promote the vocational and societal relevance of chemistry in the context of circular economy are developed based on research in collaboration with schools, the university and industry. In the national and international StarT project (https://start.luma.fi/en/), project-based learning is being promoted collaboratively with over 50 collaborative partners. More examples can be found for example in the online book *(Aksela, Oikkonen & Halonen, 2018).*

Most development projects that are implemented in the LUMA system are connected to theses in different stages of teacher education, and also scientific papers are written based on them. In research concerning doctoral theses, for example the following new solutions and pedagogical innovations are produced with the help of design-based research: (i) learning games and a framework for their evaluation, (ii) inquiry-based working instructions in collaboration with future teachers and the industry, (iii) a science club model for small children's inquiry-based education, (iv) a model for teachers' educational development by using inquiry-based chemistry learning and SOLO-taxonomy, (v) a collaborative and engaging model for teacher education that promotes inquiry-based education in class teacher education, (vi) for future teachers: developing a course in the context of the Nature of Science, (vii) developing problem-based and inquiry-based laboratory work in university education and (viii) promoting molecular modelling in education.

3. Conclusions

During the years design-based research has been used in the LUMA ecosystem, it has been observed that when it is used systematically, it is a good catalyzer for research-based development of new solutions and pedagogical innovations, their implementation and collaborative and creative learning in math, science and technology education. Its implementation increases (i) relevant collaboration between schools, universities and the industry and commerce, (ii) promotes collaboration between participants that are often unknown to each other (e.g. researchers, teacher educators, industry specialists, teachers, representatives from the educational administration and future teachers) and the fact that they learn from each other, and (iii) strengthens the collaborative operating model in teacher education. It has been observed that the systematic description of design-based research (e.g. Figure 1) clarifies the aims of research-based development and stages for people, who are not as acquainted with the method, such as sponsors.

References

Aksela, M. (2005). *Supporting meaningful chemistry learning and higher-order thinking through computer-assisted inquiry: A design research approach*. Helsinki: University of Helsinki. http://ethesis.helsinki.fi/julka isut/mat/kemia/vk/aksela/sup porti.pdf

Aksela, M., & Boström, M. (2012). Supporting Students' Interest through Inquiry-Based Learning in the Context of Fuel Cells. *Mevlana International Journal of Education*, *2*(3), 53-61.

Aksela, M., & Ikävalko V-M. (2016). How to promote relevant practical work in science education through a non-formal learning environment? *Science Education Research and Practical Work: A collection of invited papers* inspired by the 23rd Symposium on Chemistry and Science Education held at the TU Dortmund University, May 26-28, 2016. Eds. Eilks, I, Markic, S. & Ralle, B. Aachen: Shaker, 2016

Aksela, M., Oikkonen, J., & Halonen, J. (Eds.) (2018). *Collaborative Science Education at the University of Helsinki since 2003: New Solutions and Pedagogical Innovations for Teaching from Early Childhood to Universities*. Helsinki: Unigrafia Oy. https://www.helsinki.fi/sites/default/files/atoms/files/isbn-978-951-51-4089-0.pdf

Aksela, M. K., Pernaa, J. I. S., Blomgren, P. I. A., & Rautiainen, I. M. (2018). *Collaborative science education at the University of Helsinki: ChemistryLab Gadolin: a science lab as an inspiring environment for learning, development and research since 2008*. Helsinki: University of Helsinki. https://www.helsinki.fi/sites/default/files/atoms/files/isbn-978-951-51-4506-2.pdf

Anderson, T., & Shattuck, J. (2012). Design-based research a decade of progress in education research? *Educational researcher*, *41*(1), 16-25.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences, 13*(1), 1–14.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141–178.

Brown, A., & Campione, J. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education* (pp. 289–325). Mahwah, NJ: Lawrence Erlbaum Associates.

Cobb, P. (2001). Supporting the improvement of learning and teaching in social and institutional context. In S. Carver & D. Klahr (Eds.),*Cognition and instruction: Twenty-five years of progress* (pp. 455–478). Cambridge, MA: Lawrence Erlbaum Associates.

Cognition and Technology Group at Vanderbilt. (1997). *The Jasper project: Lessons in curriculum, instruction, assessment, and professional development*. Mahwah, NJ: Erlbaum.

Collins, A. (1992). Towards a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology* (pp. 15–22). Berlin: Springer.

Collins, A. (1999). The changing infrastructure of education research. In E. Lagemann & L. Shulman (Eds.), *Issues in education research* (pp. 289–298). San Francisco: Jossey-Bass.

Dede, C. (2004). If design-based research is the answer, what is the question? A commentary on Collins, Joseph, and Bielaczyc; diSessa and Cobb; and Fishman, Marx, Blumenthal, Krajcik, and Soloway in the JLS special issue on design-based research.*Journal of the Learning Sciences, 13*(1), 105–114.

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher,* 5-8.

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *The Journal of the Learning Sciences, 11*, 105–121.

Kelly, A. E. (2003). Research as design. *Educational Researcher, 32* (1), 3–4.

Kelly, A. E., Lesh, R. A., & Baek, J. Y. (Eds.) (2008). *Handbook of design research in methods in education. Innovations in science, technology, engineering, and mathematics learning and teaching*. New York, NY: Routledge.

Juuti, K., & Lavonen, J. (2006). Design-based research in science education: One step towards methodology. *Nordina, 4*, 54–68.

Pernaa, J. (Ed., 2013). *Kehittämistutkimus opetusalalla* (The title: Design-based research in education in English). Juva: Bookwell Oy.

Pernaa, J., & Aksela, M. (2013). Model-Based Design Research: A Practical Method for Educational Innovations. *Advances in Business-Related Scientific Research Journal*, *4*(1), 71-83.

Richey, R. C., & Nelson, W. A. (1996). Developmental research. In D. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 1213–1245). London: Macmillan.

Sandoval, W. A., & Bell, P. (2004). Design-based research methods for studying learning in context: Introduction. *Educational Psychologist*, 39(4), 199-201.

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*, *23*(1), 18-36.

Sherin, M.G.(1998). *Developing teachers' ability to identify student conceptions during instruction*. In S. B. Berenson, K. R. Dawkins, M. Blanton, W. N. Coulombe, J. Kolb, K. Norwood, & L. Stiff (Eds.), Proceedings of the Twentieth Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education (pp. 761–767). Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

Wang, F. & Hannafin, M. J. (2004). *Using design-based research in design and research of technology-enhanced learning environments.* Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). *Educational design research*. London: Routledge. Whitehurst.

Vesterinen, V-M., & Aksela, M. (2013). Design of Chemistry Teacher Education Course on Nature of Science. *Science & Education*, *22*(9), 2193-2225.

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