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Research and design triads in the digital epoch: implications for science and technology education

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ABSTRACT: In this article, the authors present and discuss the technological design process through the design triad - a parallel entity to the research triad, which describes experimental research. In the pre-digital age, the design triad and research triad were described by schemes of different orders; in the current digital epoch, they are represented by a similar scheme. This theoretical finding is in line with the substantial interpenetration of science and technology that characterises the present time. From the educational viewpoint, the result serves as evidence of the need to adopt an interdisciplinary educational approach that combines science and technology and focuses on hybrid systems.

Keywords: Technology education, science education, interdisciplinary education, digital epoch, design triad, research triad

INTRODUCTION

It is customary to describe experimental research by the research triad, which consists of the following components: a subject (researcher), research tools and an object (object of research) [1]. Classical experimental research before the digital age was characterised by both the subject and object being natural, whereas the research instruments were technological.

In the current digital epoch, the component describing the object is no longer completely natural, but includes an artificial part that is mostly digital, such as a cyber-physical system [2][3]. Therefore, the classical description no longer represents the contemporary research triad and should be converted into another form [1].

The consequences of this change with regards to science education are reflected, *inter alia*, in the need to adopt a model of inquiry-based learning of hybrid systems through using emerging digital technologies. This is instead of classical learning methods, where students study natural phenomena or processes with equipment based on amplification or/and transformation of energy [1].

As mentioned above, discussion in the literature focuses on experimental research and science education. The purpose of this theoretical article is to propose a parallel analysis in the realm of technological design and technology education, and to compare the findings to those obtained for experimental research and science education. To the best of the available knowledge, such an analysis is being performed here for the first time.

The structure of the article is as follows. First, the authors present the research triad and describe how its nature has changed in the transition from the pre-digital age to the digital era. Then, the design triad is defined and characterised in the different periods. Finally, the implications are discussed, with regards to science and technology education.

RESEARCH TRIAD

The basic assumption in this discussion is that experimental research can be represented through the following research triad: a subject (researcher), research instruments and an object (object of research) [1]. In the pre-digital period, both the subject and object were natural, whereas the research tools were technological. Therefore, the pre-digital research triad can be described through the *nature-technology-nature* scheme. This scheme, where technology is confined by nature on both sides, is in line with the first-order scheme proposed by Floridi to describe the interaction between experimental research and technology [4]. In this scheme, there is a single technological component (research tools) through which the (natural) subject studies a natural object, process or phenomenon.

It is important to mention that in higher-order schemes, the technological component occurs more than once [5]. Thus, for example, the second-order scheme of *nature-technology-technology* describes a situation where the natural object is replaced by a completely artificial object. In the third-order scheme of *technology-technology-technology*, the case is where the human researcher is replaced by an artificial entity, such as artificial intelligence (Table 1).

Table 1: Interaction between research and technology - Floridi's schemes.

Order	Scheme
1st	Nature - technology - nature
2nd	Nature - technology - technology
3rd	Technology - technology - technology

In the digital epoch, the component that describes the object is no longer completely natural, but includes an artificial part that is mostly digital [2]. Therefore, the first-order scheme described above no longer matches the description of the contemporary experimental research triad, and should be converted into a new scheme, *nature-technology-hybrid* [1]. This scheme can be interpreted as an intermediate level between the first-order and the second-order schemes.

The new scheme, which emphasises the importance of hybrid systems, is in line with the Industry 4.0 framework [6]. According to this, one of the fundamental building blocks of the fourth industrial revolution is the so-called cyber-physical system [7]. The term, cyber-physical systems, is used for a new generation of systems integrating computational and physical components that can interact with humans, the surrounding world and the global network. This ability is a key factor for future technological progress [8].

It is important to note that the transition between the pre-digital age and the digital epoch was not a sharp one, but a gradual process taking place concurrently with developments in digital technology [1]. However, in this article the intermediate phase is not addressed.

DESIGN TRIAD

Similarly to the representation of experimental research through the research triad, the authors propose to describe technological design with the design triad, which is also comprised of a subject, tools and an object. The subject in this case is an engineer, the instruments are design tools, and the object is a prototype or product.

In the pre-digital age, the engineer would design new (or improved) technological systems by using various design tools. The relevant scheme is a second-order scheme, i.e. *nature-technology-technology*. Therefore, in the pre-digital epoch, experimental research and technological design were characterised by schemes of different orders (first-order and second-order scheme, respectively). Indeed, experimental research was formerly perceived as essentially different from technological design. Thus, for example, the scientist was perceived as motivated by curiosity, seeking a precise general solution and aiming for perfection, whereas the engineer was perceived as driven by a need, seeking an approximate particular solution and aiming for an optimum [9].

In the digital era, the object of the design process is no longer purely artificial but includes a natural component, such as a cyber-physical system. Therefore, the second-order scheme should be abandoned, and the *nature-technology-hybrid* scheme should be adopted.

This scheme, which describes contemporary technological design, is the same scheme that represents today's experimental research, mentioned in the previous section. The conclusion is that in the digital epoch, experimental research and technological design are represented by a similar scheme, which will be referred to below as the digital scheme (Table 2). This result indicates the phenomenon of the interpenetration of science and technology, which takes place in the current period; a process that has been discussed elsewhere [10].

EDUCATIONAL IMPLICATIONS

As covered above, in the pre-digital epoch, experimental research and technological design were characterised by schemes of different orders and were perceived as essentially different from each other. As the characteristics of scientific research and technological design should be reflected in education, in the pre-digital age, science education and technology education would be supposed to be distinct from each other. Indeed, in classical technology education students designed technological systems (e.g. via project-based learning) [11][12], as opposed to their peers who studied natural phenomena (e.g. via inquiry-based learning) [13][14].

Table 2: Research triad, design triad and digital scheme.

	Scientific research (experimental)	Technological design
Triad	Researcher - research tools - object of research	Engineer - design tools - prototype/ product
Pre-digital scheme	Nature - technology - nature (1st order scheme)	Nature - technology - technology (2nd order scheme)
Digital scheme	Nature - technology - hybrid (intermediate level scheme)	

In the digital era, the third component - object - in both the research triad and the design triad is changed and turns into a cyber-physical system. The authors interpret these phenomena as the interpenetration of science and technology, and of research methodologies and design methodologies. Obviously, in such a situation, the distinction between science education and technology education is no longer valid. In light of that, and for the purpose of providing students with a skills set that is suitable for the current period, it is recommended to adopt an interdisciplinary educational approach that combines science and technology [15-17] and focuses on hybrid systems.

An example of this is the connected gardening project. In this educational activity, students cultivated a garden with plants that had sensors attached to them. These sensors measured various parameters and transmitted relevant information between themselves and a cloud storage system. Based on observations of the plants and an analysis of the information obtained from the sensors, the students experienced inquiry-based learning of a cyber-physical system [18]. The authors' recommendation to focus on hybrid systems is further validated by the fact that cyber-physical systems constitute, as covered above, one of the fundamental building blocks of the Industry 4.0 framework [6].

SUMMARY

In this article, the authors defined the design triad, which describes the technological design process through an analogy to the research triad that reflects experimental research. In the pre-digital age, the research triad was represented by a first-order scheme; namely, *nature-technology-nature*, whereas the design triad was described by the second-order scheme of *nature-technology-technology*. This result is in keeping with the fact that experimental research was formerly perceived as essentially different from technological design.

However, in the digital epoch both triads are described by a similar scheme, the digital scheme, i.e. *nature-technology-hybrid*. This theoretical finding serves as evidence of the considerable interpenetration of science and technology in the current period, and reinforces the importance of interdisciplinary education that combines science and technology, particularly as part of the Industry 4.0 framework.

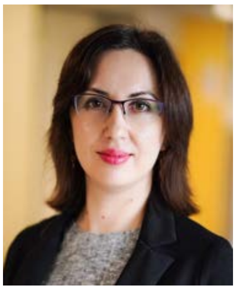
REFERENCES

1. Tsybulsky, D. and Levin, I., *Inquiry-based Science Education and the Digital Research Triad*. In: Levin, I. and Tsybulsky, D. (Eds), Digital Tools and Solutions for Inquiry-Based STEM Learning. IGI Global, 140-165 (2017).
2. Ess, C., *The Onlife Manifesto: Philosophical Backgrounds, Media Usages, and the Futures of Democracy and Equality*. In: Floridi, L. (Ed), The Onlife Manifesto: being Human in a Hyperconnected Era, Springer, 89-109 (2015).
3. Levin, I., Cyber-physical systems as a cultural phenomenon. *Inter. J. of Design Sciences and Technol.*, 22, **1**, 67-80 (2016).
4. Floridi, L., Technology's in-betweenness. *Phil. and Technol.*, 26, **2**, 111-115 (2013).
5. Floridi, L., *The Fourth Revolution: how the Infosphere is Reshaping Human Reality*. Oxford University Press (2014).
6. Schwab, K., *The Fourth Industrial Revolution*. Crown Business (2017).
7. Jazdi, N., Cyber physical systems in the context of Industry 4.0. *Proc. IEEE Inter. Conf. on Auto., Qual. Test., Robot*., IEEE, 1-4 (2014).
8. Baheti, R. and Gill, H., Cyber-physical systems. *Imp. Cont. Technol.*, 12, **1**, 161-166 (2011).
9. Waks, S., Science-technology dimensions in physics education: prospects and impact. *Physics Educ.*, 29, **2**, 64-70 (1994).
10. Gero, A., Students' attitudes towards interdisciplinary education: a course on interdisciplinary aspects of science and engineering education. *European J. of Engng. Educ.*, 42, **3**, 260-270 (2017).
11. Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D. and Leifer, L.J., Engineering design thinking, teaching, and learning. *J. of Engng. Educ.*, 94, **1**, 103-120 (2005).
12. Gavin, K., Case study of a project-based learning course in civil engineering design. *European J. of Engng. Educ.*, 36, **6**, 547-558 (2011).
13. Abd El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N.G., Mamlok-Naaman, R., Hofstein, A. and Tuan, H.L., Inquiry in science education: international perspectives. *Science Educ.*, 88, **3**, 397-419 (2004).

14. Gormally, C., Brickman, P., Hallar, B. and Armstrong, N., Effects of inquiry-based learning on students' science literacy skills and confidence. *Inter. J. for Scholarship of Teaching and Learning*, 3, **2**, 16 (2009).
15. Sohn, S.Y. and Ju, Y.H., Design and implementation of youth engineering adventure program in Korea. *Inter. J. of Engng. Educ.*, 27, **5**, 1107-1116 (2011).
16. Ryńska, E.D., Interdisciplinary training within the education curricula for architects and engineers. *Global J. of Engng. Educ.*, 18, **3**, 202-206 (2016).
17. Gero, A. and Danino, O., High-school course on engineering design: Enhancement of students' motivation and development of systems thinking skills. *Inter. J. of Engng. Educ.*, 32, **1A**, 100-110 (2016).
18. Zuiker, S.J. and Wright, K., Learning in and beyond school gardens with cyber-physical systems. *Inter. Learn. Environ.*, 23, **5**, 556-577 (2015).

BIOGRAPHIES

Aharon Gero holds a BA in physics (*Summa Cum Laude*), a BSc in electrical engineering (*Cum Laude*), an MSc in electrical engineering, and a PhD in theoretical physics, all from the Technion - Israel Institute of Technology, Haifa, Israel. In addition, he has an MBA (*Cum Laude*) from the University of Haifa, Israel. Dr Gero is an Assistant Professor in the Department of Education in Technology and Science at the Technion, where he heads the Electrical Engineering Education Research Group. Before joining the Technion, he was an instructor at the Israeli Air-Force Flight Academy. Dr Gero's research focuses on electrical engineering education and interdisciplinary education that combines physics with electronics, at both the high school and higher education levels. Dr Gero has received the Israeli Air-Force Flight Academy Award for Outstanding Instructor twice and the Technion's Award for Excellence in Teaching eleven times. In 2006, he received the Israeli Air-Force Commander's Award for Excellence, and in 2016 was awarded the Yanai Prize for Excellence in Academic Education.



Dina Tsybulsky graduated from the Hebrew University of Jerusalem, Israel, with a PhD in science education in 2014. From 2015 to 2017, she was a postdoctoral fellow at the School of Education of Tel Aviv University. At present, Dr Tsybulsky is an Assistant Professor and Head of the Biology Education Research Group in the Faculty of Education in Science and Technology at the Technion - Israel Institute of Technology, Haifa, Israel. Dr Tsybulsky serves at the National Association for Research in Science Teaching (NARST) as a member of the Programme Committee and as a Co-chair of the History, Philosophy and Sociology of Science Research Strand. Presently, she is a PI of the research grant of the Israeli Science Foundation. Dr Tsybulsky's research interests include: inquiry-based biology learning; nature of science and scientific practices; science education and teacher preparation in the digital age.

Ilya Levin received his PhD degree in computer engineering in 1987 from the Institute of Computer Technologies at the Latvian Academy of Science. From 1987, he was the Head of the Computer Science Department in the Leningrad Institute of New Technologies (in the former USSR). He moved to Israel in 1990. Between 1993 and 1997, Ilya Levin was the Head of the Computer Systems Department at the Holon Institute of Technology. In 1997, he worked as a Research Fellow in the Computer Science Department of the University of Massachusetts. During four years, between 2003 and 2006, Dr Levin was an Associate Professor of the School of Engineering in the Bar Ilan University, Israel. In 2014 and 2018, he was a Visiting Professor in Ca' Foscari University of Venice. At present, Dr Levin is a Full Professor in the School of Education of Tel Aviv University in Israel. His recent research interests include: computer design; cultural studies of information society; and science and technology education. Dr Levin is the author of about 180 research papers, both in computer engineering and in the humanities.