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Scientific Inquiry in the Digital Age

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Abstract

The paper is addressed the ways in which scientists obtain new knowledge in Digital Age and how these new ways are manifested in science education. The paper deals with the classical triad of experimental research, 'subject-instrument-object', and study a so-called digital triad, which is an experimental research triad of digital society. The digital triad differs from the classical triad in three ways: (1) the subject in the role of a new type of researcher – a so-called digital scholar; (2) the experimental instrument is based on mobile and wearable; and (3) a new type of objects – hybrid natural-artificial objects. The proposed interpretation of the digital triad presents transformations in inquiry-based science education. Analyzing a number of pioneer projects, the paper discuss how digital transformations are manifested in certain educational practices.

1. Introduction

Global society has transitioned into the Digital Age; this shift represents a revolution in human history – the so-called digital revolution ([1], [2], [3], [4]). This revolution relates to fundamental principles of human being including the emergence of the informational abundance, transforming ways of observation of the world, and a changing view on the nature of surrounding objects. Obviously, these transformations could not possible leave unchanged key components of human culture as scientific inquiry. Scientific experiments are changing with emerging technologies; this change contributes to an epistemological breakthrough and to the construction of knowledge [5].

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2. The Digital Triad in Experimental Science

Any traditional experimental scientific research comprises three fundamental components: (1) a research subject (researcher); (2) an instrument of research (experimental equipment); and (3) an object of research (natural objects, processes, or phenomena). The paper focuses on the classical experimental triad, subject-instrument-object transformed according to fundamental changes of the society moving to Digital Age. For simplicity, we refer to the research triad of the digital epoch as the digital triad.

The first component of the digital triad, the experimental subject/researcher, has altogether transformed in the digital epoch. First of all, such new researchers are inhabitants of the digital society. Their scientific activities are digitally inspired, including intensive collaboration and data exchanges with colleagues, experimental research based on analysis of 'big data' and other emerging scientific undertakings. Moreover, the professional identities of such researchers are expressed in the virtual space. Their collaboration with colleagues takes place mainly online.

Science nowadays is increasingly collaborative ([6], [7]). Thus, scientific research has become both data-intensive and highly dependent on intensive communications. Many web-based resources supporting experimental research become available. The new researchers of the digital epoch are able to integrate raw data received from different resources into their own research, applying big data analysis and network analytic methods.

Measurement in particular has changed in the digital epoch, with the emergence of a so-called sensor revolution. The emerging smart sensors are not merely measurement devices in the traditional sense, which can transfer a value of a specific parameter from an object to the researcher by performing analog to digital transformation. The new sensors, interconnected online, are adapted to receive

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and/or process information from a cloud memory and other resources, so as to provide the researcher with the desirable meaningful data beyond just rough values.
Among the emerging technologies supporting the above-mentioned innovations are mobile and wearable devices, as well as ubiquitous computing. Such technologies include context-aware computing, ubiquitous wireless networks, smart objects, and location-based systems. Ubiquitous computing involves the most natural possible interaction between a user and a computer, geared towards the ultimate aim of the user not even realizing that s/he is interacting with a system [8].
We argue that the third component of the digital triad – the research object – is no longer purely natural. The new object of research may be comprised of an artificial portion, which is mainly a digital one. In other words, the object becomes a hybrid one with functions partially based on natural laws and partially grounded in the technological specification of the digital devise embedded within it.
One of the clear manifestations of the new object of research is emergence of a cyber-physical system (CPS). CPSs are hybrid natural/artificial systems that humans create by providing systems with an ability to behave socially. The emergence of the CPS is an important cultural phenomenon of digital society [9]. CPSs comprise an example of objects that cannot be attributed to either nature or technology, since they contain both natural and artificial components.

3. The Digital Triad in Educational Projects: A Few Case Studies

In a science class, the research triad is reflected in inquiry-based science education. We consider students as subjects of the triad that engage in inquiry-type investigational activities and analyze three specific educational inquiry-based science projects in order to study how the digital triad is implemented in science education.
The first project involves a location-based, augmented reality environment with a five-step guiding mechanism custom-developed so as to guide students in sharing knowledge during inquiry-based learning [10]. In this project, fourth-grade students from an elementary school in North Taiwan studied the ecological environment at a nearby pond. Specifically, students physically observed the habitats and morphology of selected aquatic plants by using a location-based Augmented Reality system. This project clearly illustrates changes that take place at the *subject* component of the digital triad, associated with a high level of inquiry-oriented student collaboration. Such effective collaboration proved possible due to the abundance and availability of scientific knowledge regarding to the learning topic. Through such inquiry-based learning processes, students form their own online personalities as researches connected by a network. New technologies have enabled this innovative learning activity – above all, the emerging communication technologies and cloud technologies playing a revolutionary role in today's scientific inquiry.
The second project is the 'G-Physics' program, which utilizes a Google Glass application for a standard high school acoustics experiment: determining the relationship between the tone frequency generated by hitting a glass filled with water and the amount of water in the glass [11]. The project requires that students conduct experiments interactively, that they manipulate the theoretical representation of the relevant phenomena, and, simultaneously, that they interact with real-world phenomena. The inquiry activities in this project mainly involve the *instrumental* component of the digital triad. The use of Google Glass as a virtual component in the study enables research regarding multiple objects by observing and manipulating them in reality and by enhancing the inquiry virtually.
Finally, the Connected Gardening Project [12] reflects the changes of interest in the *object* component of the triad. In this project, a fourth-grade class organizes and refines its garden plot using observations of the physical environment and evaluations of data from a networked digital probe. In this way, the probe and the plot together form at least one specific cyber-physical system that visualizes and provides access to some parameters of the garden's soil, water, and sunlight. In turn, the data further allows students to display the garden system according to its underlying physical markers of plants growth, as well as to experience the patterns and processes involved in dynamically balancing the garden system. This program is based on the ability of the plants, by means of the various sensors they were attached to, to transfer data both between the objects and from the objects to the cloud memory. Hence, the main feature of the project is the fact that the objects (the plants in the garden) are no longer the purely natural entities they would have been in the pre-digital epoch. As CPSs, these objects are hybrid natural-artificial systems that are able to transfer a substantial amount of data. Moreover, the objects demonstrate some basic social behavior. The emergence and use of such hybrid systems as the objects of scientific inquiry is unprecedented in science education.

4. Conclusion

In the paper, a study that has arisen at the intersection of areas of scientific experiment and emerging digital technologies is presented. The study considers an experimental research triad *subject-instrument-object* as comprising the core foundation of experimental science. The intrinsic presence of technological components as integral parts of the triad determines inevitability of transforming the triad in the new digital environment, in turn stimulating the study of these changes. Each component of the digital triad is enriched by particular features that are specific to the digital epoch: intensive communication as a feature of the research subject, virtualization as a feature of the research instrument, and not merely physical but rather hybrid features of the emerging research objects.
The digital triad is integrated into science education in the form of inquiry-based learning activities. New hyper-connected students (researchers), digital instruments, and hybrid research objects are gradually introduced into educational institutions. A number of successful, innovative educational projects confirm this transformation.
The main contribution of the lies in its proposed approach towards the analysis of transformations in experimental science. Applying this approach in analyzing the digitalization of contemporary scientific research will yield understandings regarding both experimental science and science education.

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