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Constructing Scientific Notions: Students' Conceptual Change

Abstract

Students' cognitive representation means the establishment of cognitive frames. This article explores how students construct notions by interacting with their conceptual understanding. Our research question focused on how students represented scientific contexts through the concept of "Learning Science Through Theatre" Initiative. We focused on and analyzed students' representations both by quantitative and qualitative methods. Analyses revealed students' need to disentangling conceptual aspects of explanation. This program creates a network of knowledge and collaboration in which students focus on the mental schemata with respect to RRI Principles. All the theatrical performances during three (3) school years from 2014 to 2017 were organized by school students (2500) and embed scientific concepts, creative and art techniques and cultural/ social elements.

Keywords: Scientific Notion, Conceptual Understanding, Cognitive Schemes, RRI

Introduction

According to recent researches, when students try to acquire a scientific notion, a conceptual change is made [1], but we have to research what internal mechanisms are made for conceptual understanding. Semiotic systems can offer the appropriate ground to examine students' cognition, as the coexistence of multiple cognitive systems [2,3,4] can help researchers to understand the mechanism of cognition.

Mechanisms of Cognitive Development (CD)

In an attempt to clarify the internal mechanisms in students' brain, diSessa (2014) [5] assumes that mechanisms provide basic principles by which

change happens, therefore particular mechanisms are deeply dependent on the relevant theoretical framework for describing knowledge. The cognitive system is self-organized, given its original characteristics, evolving to equilibrium states, otherwise we lead to negative learning out-comes [6].

The role of Representation and Cognitive Schemes and Frames

Students' conception is a constantly evolving system. "Representational systems" include systems of spoken and written symbols, static figural models or pictures, manipulative models and real-world situations. The content is specific, but not limited. [7]. Tszetkov (2014) [1] has categorized this cognitive procedure into perception, processing and representation. Nehring, et all. (2017) [8] specifies cognitive procedure by the categories of integration, organization, selection and reproduction. The physical world consists of matter and energy and the abstract world consists of information and intelligence [9]. Moreover, Yao (2009) [10] tries to connect the external data of notions and the internal representation from students by describing the information processing triangle with the corners of abstract, brain and machines. Conceptual concepts are not initially shaped [8] but gradually enriched during the learning process. The organization of knowledge is achieved through the frames that are used to lead to the hyperlinks of knowledge [11]. This cognitive apparatus is divided into three main categories: a) cognitive context, b) emotional context, c) socio-cultural context [12].

A Theoretical Model of Shaping Cognitive Schemes

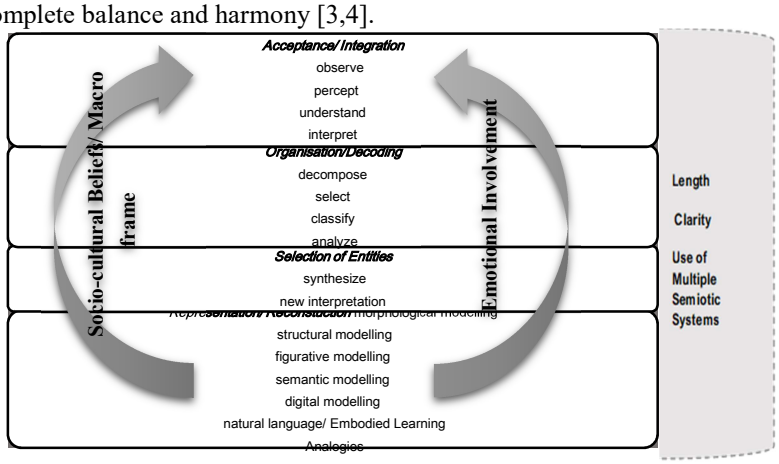
Hypothesis, Aim of the Study

In this section we present CS-Model of conceptual and perceptual processes, to explain the way that cognitive schemes are shaped. Our theoretical model has its origins on researchers' theoretical frameworks focusing on cognitive development [1,8,9,10]. The main characteristic of these researches is that the procedure of cognitive schemes begins through the external observation, then it has to be reorganized through internal procedures, and then students have to represent scientific notions in an understandable way related to epistemic cognition. The proposed model of cognition is categorized into four stages:

1. Acceptance/ Integration: After the observation phase, students try to percept each notion finding their core elements. Students have made a first coding on their previous beliefs to new entities and as a result they can interact with their environment. The term responsiveness is used to suggest that students respond to the task by becoming actively engaged in.
2. Organization/ Decoding: Students make efforts to decompose elements of each scientific notion, select them and classify them into categories of common meaning, organizing their cognitive field.

3. Selection of Entities: The effort of synthesis and a new, better interpretation of notion are established on this phase. Students make conceptual and categorical assumptions in an attempt to establish their new cognitive frames.

4. Representation/ Reconstruction: All representational systems have to be in complete balance and harmony [3,4].



Natural World (RRI Principles) ⟶ Abstract Word (Socio-scientific concepts)

Fig.1. The CS-Model of Cognitive Development

Cognitive Development in the concept of Responsible Research and Innovation

Semiotic analysis takes into account the factor of cultural identity, but it has not been studied how the cultural context affects the formation of cognitive structures. The conceptual ecology describes how the cultural beliefs affects the intake of knowledge. Sociomateriality declares that the material world interacts with cultural identity [14]. Science education answers to a significant question: "How could science education play an important role to address societal challenges and how can all the stakeholders open schools to society?". The integration of Responsible Research and Innovation (RRI) principles in educative contexts can be strongly beneficial for students, as it supports them in the development of critical thinking and collaborative learning skills while accommodating multidisciplinary and stronger student engagement. Hence, it is essential to lay out principles that will help on the implementation of RRI in teaching and learning activities in schools. This can be done through a number of pedagogical methods such as inquiry-based learning, structured research school projects or through reflections on ethical, legal and social aspects (ELSA) and basic socio-scientific issues (SSI). The methodology of Learning Science Through Theater is integrating creativity, art and science education following a proposed creative inquiry-based learning scheme that at the same time fulfilling the RRI principles. The principles of RRI, according to the European Commission, are [15]:

1. **Governance:** Addresses the responsibility of policymakers to prevent harmful or unethical developments in research and innovation. The latter is a fundamental basis for the development of the rest of the dimensions.
2. **Public Engagement:** It implies that societal challenges should be framed on the basis of widely representative social, economic and ethical concerns and common principles on the strength of joint participation of all societal actors - researchers, industry, policymakers and civil society.
3. **Gender Equality:** Addresses the underrepresentation of women, indicating that human resources management must be modernized and that the gender dimension should be integrated in the research and innovation content.
4. **Science Education:** Faces the challenge to better equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the research and innovation process.
5. **Open Access:** States that RRI must be both transparent and accessible. Free online access should be given to the results of publicly funded research (publications and data).
6. **Ethics:** Requires that research and innovation respects fundamental rights and the highest ethical standards in order to ensure increased societal relevance and acceptability of research and innovation outcomes.

For the purposes of implementation in Learning Science Through Theater initiative these principles have been integrated in the school community reality. In our approach we are using them in a way that the school managers, teachers as well as students will understand according to their everyday life in school. For this we have created and tested the following scheme (Fig. 2) about the RRI implementation in schools.

Fig. 2. The RRI implementation scheme in the context of LSTT [16].

The present study

The Learning Science Through Theatre initiative is a large scale implementation activity in Greece (http://www.lstt.eu/) that is based on the pedagogical framework which was developed by the European project CREAT-IT (http://creatit-project.eu/) and continues to be implemented in the framework of

the European Project CREATIONS (http://creations-project.eu/). It is initiated and organised by Science View (http://www.scienceview.gr/) with the scientific and pedagogical support of the National and Kapodistrian University of Athens, Faculty of Philosophy, Pedagogy and Psychology (http://en.ppp.uoa.gr/) and the cooperation of Research and Development Department of Ellinogermaniki Agogi (www.ea.gr), during the school years 2014-2017. This initiative follows the principles of the Science Education Declaration, of creativity, of effective and efficient research and aims at enhancing creativity in class-room (http://www.opendiscoveryspace.eu/community/culture-creativity-curiosity-413201) in the context of STEAM. Students engage in activities such as the writing of scientific stories (scenarios), composing music, designing sets, costumes and coming up with choreographies.

Methodology

Participants

During the years 2014-2017, 150 theatrical performances on average have been introduced to the audience, over 2500 students have participated and over 200 teachers from different cognitive domains have collaborated.

Methods

The methodology constitutes a merging of qualitative and quantitative analysis. A “mix- method design” can lead us to more specific results. We also use content-analysis, while the grounded theory is, also, preferred, as it enables as to produce a theory from data- systematically obtained and analyzed. During the procedure a registration form had held by scientific criteria so as the whole procedure was ensured an it is filled be the teachers on three different periods, one on the first phase at the beginning of the program, one in the middle, and the last one in the end of the program. The registration forms were focused on sixteen main aspect of cognitive development, Inquiry- Based principles, RRI Principles, elements of Science with and for Society, different types of representational systems, artistic elements, communicational and improvisational activities and the influence of cultural factor in students’ performances. Indicatively three of the main questions related to our theoretical framework were:**1.** Mention the students' cognitive course / process from the first moment until the first sketch, indicating 2-3 examples in each category: A. Initial ideas that remained stable, B. Initial ideas that evolved, C. Initial ideas that were rejected, D. Significant ideas that emerged in the course of action, **2.** Mention 3 examples of scientific concepts or theories or conceptual field and the three representational systems., **3.** What aspects of RRI- didactically transformed in the school environment - did you take into account your theatrical performance? The didactically transformed aspects are: a)Governance: joint involvement of researchers, industry and civil society in the theatrical performance,

b)Gender equality: Unlocking the full potential of the school, c)Ethics: Includes the social significance of scripts of theatrical performances, d) Open access: i) access to online scientific resources, ii) making available the material created by you in the educational and scientific community. Moreover, during the program pre-tests and post- tests were given and two participatory observations were held, while two workshops were organized for teachers' professional development. The "Learning Science Through Theatre" Initiative is carried out four years, from 2014-2017, but the specific paper refers to results from the first 3 years.

Results

Due to the big sample and as the research is still in progress, only few scientific notions are going to be presented in the procedure of shaping cognitive schemes. Almost 80% of theatrical performances represented scientific notions. Firstly, students tried to understand scientific notions and give their initial interpretations. For example, some students wanted to represent golden ration F. As a mathematical concept as an idea it was remained stable. In Organization/decoding phase, they understood that golden ration F is not just a mathematical concept but an observable colleration in all nature. They seem that students rejected the limitation of the use of Golden Ration F only in Mathematics and (3rd phase of Selection of Entities) they extended the concept to Physics, Biology and Astronomy. On the final phase of Reproduction/ Reconstruction, they represented the Golden Ration F with their bodies. Some schools represented the state of matter. On the first phase of integration, students try to understand the function of mass, by observing and making experiments. Their first interpretations are about the observable states of matter, solid, liquid, gas and plasma. On the phase of organization/ decoding, students started to decode the entities of each notion. They started to explain that solid constituent particles are closely packed together and solid has a definite shape. A liquid is a nearly incompressible fluid that container but retains a (nearly) constant volume independent of pressure. In a gas, the molecules have enough kinetic energy so that the effect of intermolecular forces is small. The categorization of solid, liquid, gas leaded to the third phase of selection and to the final phase of representation/ reconstruction. They represented the matter through analogies and Embodied learning, as students were in prison. Digital representations visualized the change of matter when students run around the scene.

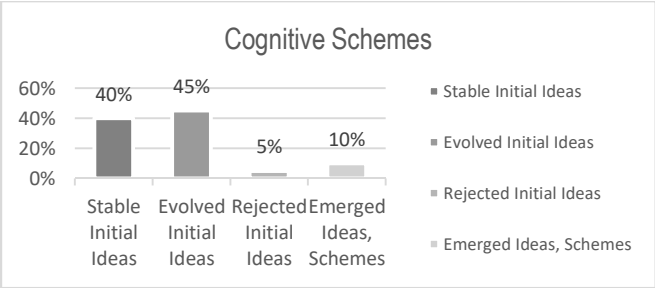


Table 1. The cognitive change of Initial Ideas.

As it is seemed from the diagram, 40% of initial students' ideas remained stable, 45% of them started to be improved and evolved during the process and 5% of their ideas were rejected. This could be in accordance to students' conceptual change. (Phase of Organization/ Decoding and Phase of Selection of Entities). 10% of students' ideas were totally new, and they are emerged during the final phase, Representation of Notions by all types of semiotic systems.

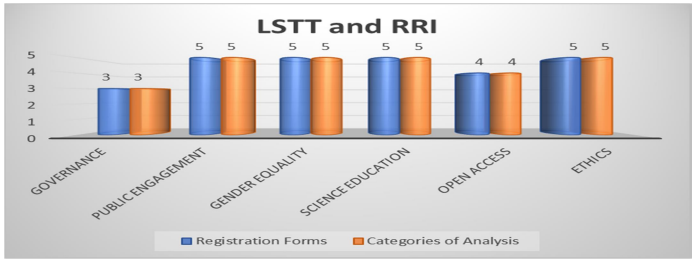


Fig. 3. The 'Learning Science Through Theatre Initiative' in the context of RRI Principles.

Our second main research question is to what extent this initiative serves the main RRI principles as an innovative research and educational program. The results show that this Initiative serves the main RRI principles (Fig.3). The science education is the main aim of the program. Almost all the teachers (95% from the answers of the registration forms) mention that the students learn how to negotiate with scientific notions. The results, as they are presented above, show that students do not only learn "by doing" but they also increase their cognitive load and science capital perspective. In the vast majority of cases, a scientific theory and its connection to theatre constituted the initial starting point for writing the script. Both the students and the whole of the school community (100%) participated in the program collaborated harmonically with each other (public engagement). Students promote citizen science and open innovation, while Science links to other subject domains and all of them cooperate to a common goal. They have to cooperate with their teachers, but also are provided with open access to research centers in order to use up-to-date information of science and communicate with re-

searchers. During the whole process, the educational community has to interact and collaborate with other agencies, for example parents, local industries etc., in order to get some advice (such as actors, directors etc.) but also to advertise their theatrical performances and find additional help for their activities (such as their customs, the music of the performance etc.). School becomes a central power which guides as many agencies as possible to achieve a common goal. Each of them contributed in a different way to each aspect of the whole procedure (social justice) and controlled each step of the performances (sustainability). All the educational, cognitive, scientific and entertaining principles had been taken into consideration throughout the program (ethics). Besides the child protection, we also try to handle the user's personal data. The discussion of ethical issues is in a total accordance to shape cognitive schemes, as in the phase of Selections of Entities and Representation/ Reconstruction students construct their cognitive fields according to the socio- cultural factor. Indicatively, some issues that were discussed, as students' new ideas were born, are: a) Human anxieties about the role of time and future evolutions, b) The position of women in science and their equal access to it as the men, c) Environmental awareness, d) The concept of interaction and cooperation between the nations, f) The role of scientific thinking in the research, g) The development of science for peaceful or military purposes. As far as open access concerned, we have to mention that the school community has access to recourses (70% of the schools) despite any economic difficulties. Therefore, we also encourage students to participate even with recorded performances. Gender equality is a crucial issue, too. This initiative recommends participating both boys and girls, by working collaboratively as a team. The registration forms indicate that an equal number of boys and girls participated in the program.

Conclusion/ Discussion

On our research we code the internal procedure of acquiring knowledge by suggesting CS- Model of cognition. The LSTT Program is able to establish a culture of scientific thinking. Students develop cooperative skills and empower an intensive interest to what happens not only inside but also outside the classroom in an entertaining way. Through cognitive development, students increase their scientific literacy according to RRI Principles. Young people have to deal with societal problems and promote research and innovation for affecting change and better life and being the agencies of their knowledge.

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