THE HUMAN IMPACT FACTOR IN THE RESEARCH AND DEVELOPMENT OF EDUCATIONAL SOFTWARE

Pavel Boytchev

ABSTRACT. This paper presents the long-term impact factor which a single person may have on a researcher. This is a description of the author's research topics and the creation of educational software, which were either directly or indirectly affected by Prof. Edward Friedman.

1. The beginning. The impact factor is a metric used to measure the importance of academic journals. This paper *is not* about this impact factor. It is about the *human impact factor*. For every researcher, there are people who have influenced his trajectory in the space of science. This impact could be direct or indirect, short-term or long-term. This paper is about a very important person, who had a notable impact on my research. This is Edward Friedman (Ed).

Some 20 years ago as a Ph.D. student at Sofia University I worked on a novel (at that time) educational environment based on the programming language Logo. This system was intended as a successor of the then existing Plane Geometry System [11], which had been developed since 1985 by ComseD and

the Educational Computer System Laboratory in Sofia University. This system provided a programming interface where students could experiment with various geometrical concepts and build their own geometrical constructions. The system was later renamed Geomland [12]. The new name was suggested by John Muirhead and Ed.

During that period of my work, the year 1999 was quite memorable. There was a total solar eclipse on August 11. It was one of the rare total solar eclipses occurring over the Balkan Peninsula. During that eclipse I was taking part in the *Bulgarian-U.S. Forum on High School Mathematics Software.*

The forum, organized by Best Practices in Education (BPE), was about sharing expertise between American and Bulgarian math teachers. Participants were educators, researchers and decision makers. Some of the most (attr)active participants in the Forum were Gail Richardson (executive director, BPE), Peter Moxhay (program director, BPE), Titu Andreescu (director of American Mathematics Competitions), John Goebel (math teacher), Bojidar Sendov (associated professor, Sofia University), Evgenia (Jenny) Sendova (researcher, Bulgarian Academy of Sciences), Svetla Boytcheva (assistant professor, Sofia University) and ... Ed (director of the Center for Innovation in Engineering and Science Education at Stevens Institute of Technology). This forum was followed by another one in 2000 and a third one in 2001 [8].

The forum was a milestone in my career. It was the first one where I took part in vivid and inspiring discussions comparing Mathematics education from both sides of the Atlantic. I had my first presentation before an international academic audience (Fig. 1) – it was about the Logo-based software system which I was developing, called Research Logo System [1].

Fig. 1. Demonstration of RLS (left); Ed and Jenny (right)

However, from a personal perspective, the most important result of this forum was the decision for a grant award from BPE for improving the Logo system. The goal was to make it sufficiently complete, so that it could be used in education and for education.

It was my first grant.

And I was eager to pursuit this new challenge.

2. The CIESE period. The grant was used to form and support a team developing a new educational system from scratch. Its name was *Elica* and it stood for *Educational Logo Interface for Creative Activities.* Later on the acronym was interpreted as *Educational Logo for Interactive Computer Animation.*

Today Elica is still the most significant result of my research. It was used to build educational applications and to generate educational content. It was used as an authoring tool in several university-level courses and was the topic of my Ph.D. thesis.

The design and the development of Elica started in 1999. The financial support of BPE was distributed over a period of two years and in late 2000 the first working version of Elica was available.

Then I reached the major milestone in my career. As a director of the Center for Innovation in Engineering and Science Education (CIESE), Ed offered me a visiting position. The task was to create educational software for some of the CIESE projects. The research environment at CIESE was something that I had never experienced before. I worked on different software applications with different members of CIESE. Everyone was friendly and supportive. The work which I did there was also used to test Elica. It was the first time Elica was used to create software that others would play with.

Actually, my stay at CIESE was full of many first-timings: it was the first time I had my birthday party abroad, it was the first time I visited New York (Fig. 2), but it was also the first time I did research in another continent, it was the first time I took part in unique and challenging activities in an international community.

The research projects manifested the core vision of CIESE about education and how to make *"engaging, authentic, and curriculum-relevant uses of the Internet by teachers and students that improve student achievement in core subjects, and that promote higher-order thinking, critical analysis, collaboration, and problem-solving"* [15].

Fig. 2. With Ed and his wife (left); with my ancestor (right)

2.1. Real data and real-time data. The first project, *Elica Navigational Vectors*, was done in collaboration with Mercedes McKay within the scope of the *CIESE Navigational Vectors* project [10]. It used several approaches for teaching vectors and vector operations. The actual topic of the project was for students to try and navigate an airplane, considering its velocity and flight direction as well as the wind's magnitude and heading. When exploring the vectors, students were supposed to use both *real-time data fetched from on-line resources about actual on-going flights and a simulated environment*, where they could practise their skills. This made an engaging link between the curriculum and Internet data, so that students could improve their performance in vectors and vector operations.
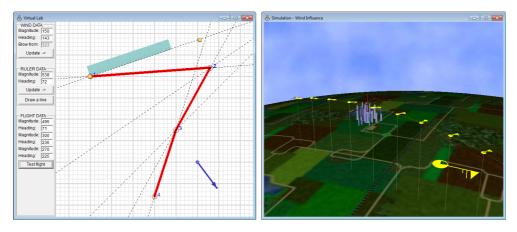

Fig. 3. Navigational Vector's virtual lab and 3D flight meteo-simulation

My responsibility was to build the software environment with Elica. The implementation was a set of several applications. The *Virtual Lab* (Fig. 3) is an exploration playground. Students solve problems on calculating the speed and direction of flights along a given list of cities. They can use a ruler, draw help lines, change the location of the cities and modify the wind factor.

The left-hand snapshot in Fig. 3 shows the actual trajectory as a thick red line, the blue arrow is the wind vector, and the ruler is along the calculated direction of the first flight. Because of the wind it is headed differently from the actual flight trajectory. The right-hand snapshot in Fig. 3 shows in 3D a meteo-simulation of a flight. The *Wind Influence* simulation was used to demonstrate the effect of wind on the flight trajectory. The application simulated different weather conditions at different locations and altitudes. Wind heading and strength are indicated by yellow meteorological symbols along the flight.

2.2. Lab exploration of processes and devices. The second project, *Elica Chromatography*, was in collaboration with Ihor Charischak. Three programs for hands-on activities were developed. The *Visible spectrum* (see Fig. 4, left) was used to experiment with light absorption and reflection. The expected result was for students to discover by themselves how these light phenomena affect the color of an object.

Paper Chromatography (Fig. 4, middle) allowed students to run paper chromatography tests [7]. The application simulated the separation of pigments that had been extracted from plant leaves. The goal was to provide a safe, realistic and rapid way to do such experiments, as well as to practice important measurement skills like determining R_f values of different pigments.
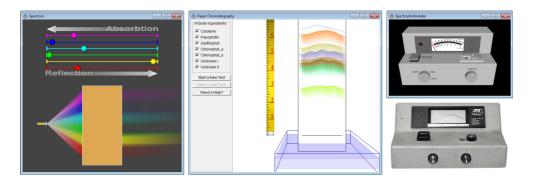

Fig. 4. Elica Chromatography applications

Students could use natural pigments, e.g., Carotene, Xanthophyll and Chlorophyll, or artificial computer-generated substances. To promote *problem-solving and creative activities* the students were encouraged to define and experiment with their own substances.

The third chromatography application was *Spectrophotometer*. This program was an interactive virtual spectrophotometer, modelled after Bausch & Lomb's Spectronic 20+ [14]. The virtual device did not only simulate the design of the real device, but also mimicked all the steps for performing analogue spectrophotometry. The program was used to gain practical skills in managing scientific experiments, adjusting measurement factors, understanding linear and logarithmic scales.

A version of the real spectrophotometer is displayed in Fig. 4, right, bottom. The virtual incarnation of the device is shown above it. Special attention was paid to achieving high resemblance. For example, both devices had light indicators, an analogue scale for absorbance and transmittance values, sample and adjustment substances, samples chamber, dials and switches.

3. The post-CIESE period. The duration of the visiting position was only 4 months. My collaboration with Ed and his colleagues at CIESE was fruitful. At that time I still had no idea of Ed's actual human impact on me. We had several conversations about my future. Ed insisted (with arguments) that I might become a good teacher, I didn't believe him. Surprisingly, some of my students, 15 years later, tell me they like my lectures ... and give me the very same arguments.

The next step of my career was not teaching, but it was again with the support of Ed. The dean of the School of Engineering at Stevens Institute of Technology, Bernard Gallois, offered me a consultant's position. My responsibilities were similar to what I did in CIESE, namely, developing software packages in collaboration with faculty members from the School of Engineering. Again the software was supposed to support *higher-order thinking and critical analysis*. It was also supposed to *engage students in creative activities* in full harmony with the *ideas of constructionism* and the *Logo philosophy*.

3.1. Trusses and other structures. The *Elica Truss Analysis* application (Fig. 5) was built in collaboration with Ed Blicharz. It was used by students from Stevens Institute of Technology and New York University to construct bridges and other truss structures.
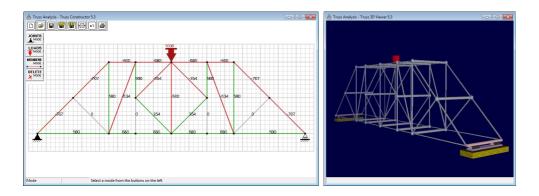
Fig. 5. Elica Truss Analysis applications

The development of this application was very instructive and not quite easy. The early versions were used by a few hundred students and there was an avalanche of bug reports. It took some time until the problems were resolved. This was a unique experience of communication on several levels – users-to-developers, students-to-educators, etc.

The implementation of the educational applications was accompanied by improvement of Elica – both activities ran in parallel. This helped Elica to become more stable in a software aspect and more useful in an academic aspect.

3.2. Thermodynamics. Another Elica-based project was *SoftLab*, developed in collaboration with Gerald Rothberg. SoftLab was a virtual laboratory environment for simulation of a true laboratory space [9]. Students could perform guided experiments or conduct their own. They could use different substances, connect various instruments (like piston, thermometers, heaters, etc.), make measurements and record the results.

The application was supposed to be used in three situations: (1) when the real lab was over-occupied; (2) when the experiment had a high risk of accident, like explosion, arson, etc.; and (3) when the resources were limited – lack of required substances, not enough time to wait for a complete experiment, etc.

The left-hand half of Fig. 6 portrays some of the instruments provided by Softlab – a calorimeter during an ice melting experiment (up), connected to mass meters, thermometers, and other digital meters; a voltmeter connected to a thermocouple, which is connected to a liquid-in-glass thermometer (down, left); three positions of a piston with a digital ruler (down, right).

The first versions of SoftLab were written in Elica, but the latest were in Java for platform independence.
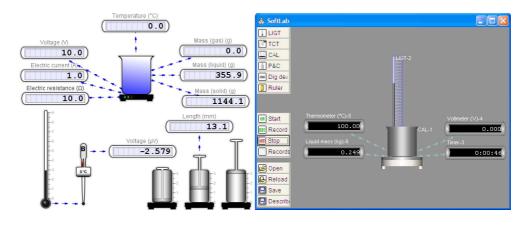
Fig. 6. Softlab application

The right-hand snapshot in Fig. 6 shows the Elica SoftLab application during an experiment of melting ice in a heater and measuring its temperature with analogue and digital thermometers.

3.3. Optics and optical systems. The third project was *Elica Optics*, developed in collaboration with Kurt Becker. This application provided a set of customizable lenses, mirror surfaces and rays. Students could arrange them to model various optical systems and optical phenomena (like Snell's law, aberration, reflection, refraction, etc). Some snapshots of the Elica Optics application are shown in Fig. 7. The left-hand one demonstrates spherical aberration – i.e., the loss of sharpness in an image caused by the shape of a spherical lens.
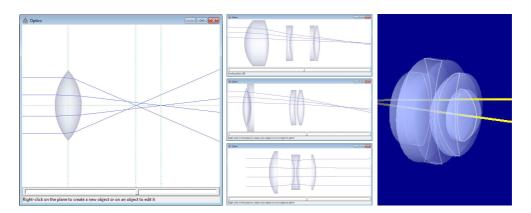

Fig. 7. Elica Optics application

The snapshots in the middle recreate three popular lens systems, from top to bottom: Zeites optical system, Petzval optical system and Tycoo optical system. The right-hand snapshot visualizes in 3D a custom lens system.

4. The post-Stevens period. Working with Ed and CIESE, and then with other faculty members from Stevens Institute of Technology, formed my research interests. My attention was directed towards building interactive educational applications where students might develop and express their skills and creativity, conduct experiments, test hypotheses, etc.

This section will describe briefly only three of these applications – *DALEST-Elica*, *Virtual Classroom* and *Mecho*.

4.1. Stereometry. Ten years ago, around 2006, I was invited by Jenny to join the DALEST project (*Developing an Active Learning Environment for Stereometry*) co-funded by the European Union under the Socrates Program, MINERVA, 2005 Selection [6].

Elica was used to build a set of 10 dynamic 3D microworlds (*Bottle Design, Cubix, Cubix Editor, Cubix Shadow, Scissors, Math Wheel, Potter's Wheel, Origami Nets, Stuffed Toys* and *Slider*) where students could construct, observe, manipulate and understand geometrical relations, ranging from rotational solid and structures with cubes to net folding and cross sections – see Fig. 8.

All of the applications were extensively used across Europe. One of them attracted a specific interest. It was the *Cubix Editor* – a tool for building structures from cubes. It was used in many activities – from art to math [13]. Some of the art constructions by young students are shown in the left-hand section of Fig. 9.

Fig. 8. Elica DALEST applications

Fig. 9. The Cubix Editor – students' models, user experiences and the new version

The success of the application was so immense that quite soon the users started to "beg" for an editor with greater capabilities. In response to this request, a new version of Cubix was implemented in 2014 – see Fig. 9, right. It supported more visual styles of the cubes (including colors, textures and symbols), worked on various platforms and made sharing of results easy.

4.2. Energy preservation. The EC FP7 weSPOT project (*Working Environment with Social and Personal Open Tools for inquiry based learning*) aims at supporting the implementation of the inquiry-based science education approach via software tools, one of which is the *Virtual Classroom* [4]. This is an interactive simulation of a classroom and its environment with specific weather conditions (sun, clouds, rain, snow). There are analogue and digital devices, air conditioners, interactive windows and a door. The students had to investigate the role of each factor (e.g., external temperature, rain, number of students, opened windows) on the energy consumption and efficiency of the classroom.

The virtual classroom model provides functionality to set up specific weather conditions and conduct experiments by tuning many factors. Fig. 10, top row, shows the classroom on a summer day and on a snowy winter night. The bottom row has photos of students, exploring individually or in teams their energy preservation hypotheses.

One of the most interesting aspects was the possibility for students to set up "impossible" situations, like snowing during a sunny 40 °C day with air conditioner turned on and a room full of jumping students.

Fig. 10. The Virtual Classroom (top) and students using it (bottom)

What the software did was just implement a few fundamental physics laws letting the whole system reach equilibrium by itself.

4.3. Geometry of motion. The last project to discuss in this paper is an authoring tool for university students. This tool allows them to build and animate virtual mechanisms [2]. This activity is part of the Geometry of motion course at the Faculty of Mathematics and Informatics. The tool's name is *Mecho – Mechanical Objects*.

The first version of Mecho was implemented in Elica in 2010. To reach higher performance, in 2014 Mecho was rewritten in C++ [3], and in 2016 yet a new version was made – in HTML5, JavaScript and WebGL, so that Mecho is now available on both desktop and mobile platforms. The design of Mecho follows closely the *vision of constructionism*. It resolves four barriers that students face: *learning*, *conceptual*, *mathematical* and *procedural* barrier [5].

The Mecho software provides access to several fundamental mechanical objects, like gears, beams, rods, etc. Then the user writes programs (within web pages) that build and animate a virtual mechanism. Fig. 11 shows two models used in the lectures – the one on the left is a mixer (blender) with a low to average complexity; the one on the right is a human skeleton with a high complexity of joints.
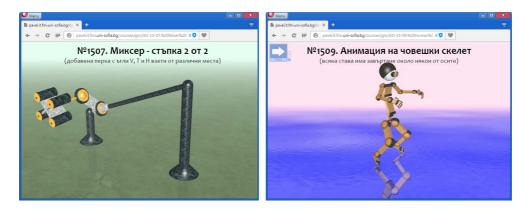
Fig. 11. The JavaScript+WebGL version of Mecho

5. Conclusion. In the last decade and a half I have created a few dozens of educational applications and over a thousand programs for generation of educational content. Looking back at the past events, Prof. Edward Friedman stands out as one of the most influential persons in and for my career. With his broad interests he taught me valuable lessons in respect to improving students' motivation and achievements, promoting both critical and creative thinking, engaging students in collaboration and problem-solving activities. Ed believed in me, but I believed in Ed, so I started to believe myself.

Acknowledgments. The work described in this paper would be impossible without the impact of Prof. Edward Friedman. Thank you, Ed.

REFERENCES

[1] BOYTCHEV P. Overview of Research Logo System. In: Proceedings of 8th International PEG Conference – Meeting the challenges of the new technologies, 1997, 30–37.

[2] BOYTCHEV P., E. SENDOVA, E. KOVATCHEVA. Geometry of Motion – Educational Aspects and Challenges. *International Journal on Information Technologies and Security (IJITS)*, Year **III** (2011), No 1, 27–40.

[3] BOYTCHEV P. Mecho – Educational Software for Virtual Mathematical Devices. In: Proceedings of 3rd EDUvision International Conference, EDUvision 2013, 692–707.

[4] Boytchev P., E. Stefanova, N. Nikolova, K. Stefanov. The Virtual Classroom – A Pilot Case in Inquiry Based Learning. In: Proceedings of 6th International Conference on Computer Supported Education – CSEDU 2014, **2** (2014), 264–269.

[5] Boytchev P. Constructionism and Deconstructionism. *Constructivist Foundations: Special issue "Constructionism and creativity"*, **10** (2015), No 3, 355–363.

[6] Christou C., E. Sendova, J. F. Matos, K. Jones, T. Zachariades, D. Pitta-Pantazi, N. Mousoulides, M. Pittalis, P. Boytchev, M. Mesquita, T. Chehlarova, C. Lozanov. Stereometry Activities with Dalest. University of Cyprus, Nicosia, 2007.

[7] Clark J. Paper chromatography. `http://www.chemguide.co.uk/analysis/chromatography/paper.html`, July 2016.

[8] Richardson G. How can we know the dancer from the dance – reflections on cross-cultural exchanges in Mathematics education. In: Proceedings of Thirty First Spring Conference of the Union of Bulgarian Mathematicians, 2002, 48–50.

[9] Rothberg G., P. Boytchev. SoftLab Virtual Laboratory Environment. Thermodynamics Examples. In: Proceedings of Annual Conference of American Society for Engineering Education, ASEE'2007.

[10] Sayres J. Navigational Vectors Project – A CIESE Realtime Data Project. `http://www.k12science.org/curriculum/vectors`, July 2016.

[11] Sendov B., D. Dicheva. A Mathematical Laboratory in Logo Style. In: F. Lovis, E. D. Tagg (eds). Computers in Education, IFIP, ECCE'88, Amsterdam, North-Holland, 1988, 213–217.

[12] Sendov B., E. Sendova. Tuning a logo-like environment to a knowledge domain. In: Proceedings of the 6th EUROLOGO Conference, EUROLOGO'97, 1997.

[13] Sendova E., T. Chehlarova, P. Boytchev. Words are Silver, Mouse-Clicks are Gold? (or how to optimize the level of language formalization of young students in a Logo-based cubics world). *Informatics in Education*, **6** (2007), No 2, 411–428.

[14] Thermo Fisher Schientific SPECTRONIC$^{\text{TM}}$ 20+ and SPECTRONIC 20D+
     User guide, 2007. `fg.cns.utexas.edu/fg/course_notebook_appendix_ii_files/Spectronic_20_D.pdf`, July 2016.

[15] YEPES-BARAYA M. Improving teaching and learning in K-12 education
     through meaningful technology integration. Presentation to U.S. Depart-
     ment of Education Panel of reviewers, 2001. `www.ciese.org/papers/_vti_cnf/doe_presentation_short.ppt`, July 2016.

Pavel Boytchev
Faculty of Mathematics and Informatics
Sofia University "St. Kliment Ohridski"
5, James Bourchier Blvd
1164 Sofia, Bulgaria
e-mail: `boytchev@fmi.uni-sofia.bg`