Acta Universitatis Nicolai Copernici • Pedagogika XXXVII/1/2019
Nauki Humanistyczno-Społeczne • Zeszyt 447

DOI: http://dx.doi.org/10.12775/AUNC_PED.2019.011

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Constructivistic didactics in physics: implementations

Abstract:

Cognitive strategies in teaching physics in Poland were first introduced in the late 1990s. The first exhibition in the interactive form was devoted to interactive physics – "Physics and Toys" in 1998 and "Contemporary Physics" in 2003 (founded at the Pomeranian University in Słupsk). Later, more comprehensive, inter-disciplinary exhibitions were created at the Nicolaus Copernicus University. The success of this teaching method exceeded our expectations. Here, we discuss the principles and practical methods of innovative didactics based on constructivist and cognitive theories; the two main paradigms of this teaching method are based on constructing the knowledge and competences of students (listeners, students) with interactive narration and using real teaching subjects that can be pulled out of one's pocket. We call these concepts hyper-constructivism and neo-realism.

Keywords: innovative didactics, constructivism, cognitivism, interactive teaching

Streszczenie:

Strategie kognitywne w nauczaniu fizyki w Polsce po raz pierwszy wprowadzono pod koniec lat 90 – tych XX wieku. Pierwsze interaktywne wystawy były poświęcone fizyce interaktywnej – „Fizyka i zabawki" w 1998 r. oraz „Fizyka współczesna" w 2003 r. (zorganizowana na Akademii Pomorskiej w Słupsku). Później na Uniwersytecie Mikołaja Kopernika powstały bardziej kompleksowe, interdyscyplinarne wystawy. Sukces tej metody nauczania przekroczył nasze oczekiwania. Omawiamy zasady i metody praktyczne dydaktyki innowacyjnej, oparte na teoriach konstruktywistycznych i poznawczych. Dwa główne paradygmaty tej metody nauczania polegają na budowaniu wiedzy i kompetencji uczniów (słuchaczy, studentów) poprzez narrację interaktywną oraz na wykorzystaniu rzeczywistych przedmiotów nauczania, które można wyciągnąć z kieszeni. Podejścia te nazywamy hiperkonstruktywizmem i neorealizmem.

Słowa kluczowe: dydaktyka innowacyjna, konstruktywizm, kognitywizm, nauczanie interaktywne.

1. Introduction

The constructivistic approach to didactics is not new. As noticed by Piero Crispiani[1], all great "teachers" from Buddha to Gandhi used slow, step-by-step didactics, giving visual examples and constructing the narration with their disciples. In *Didattica Magna*, Comenius postulated the use of pictures, flowers, drawings. For him, didactics is not a mere science about teaching (Greek: *didacto*) but rather about teaching in a manner which is 'fast, long-lasting and pleasant'.

The term "constructivistic" appeared during the 1930s with Jean Piaget's observation of how newly-born children construct their image of the world day-to-day[2]. The term "cognitivistic" appeared in the 1950s through Jerome Bruner[3], who with the advent of early computers com-

[1] P. Crispiani, *Didattica cognitivista*, Roma 2004.
[2] J. Piaget*, The construction of the reality in the child*, London 1954.
[3] J. Bruner, *Actual minds, possible worlds*, Cambridge 1986.

bined psychology, cybernetics and linguistics[4] into a unique science exploring the picture of the world in the human mind.

In the 21st century the inflation of information, its pan-accessibility and the rapidity of changes requires urgent implementations of different constructivistic and cognitivistic ideas. Quite a long time ago, we[5] developed new implementations of constructivism, based on direct participation of pupils and the use of real and simple experimental objects (instead of schemes and drawings).

The main theoretical principles of this didactics, which we call hyper-constructivistic, has been described in our previous papers[6],[7],[8]. In brief, this didactics relies in constructing the knowledge with the *group* of pupils/students/visitors using hands-on physical objects and the already-gained notions of the public (for example from the internet). The mind of the pupil is not only the target of teaching, but also a *mean* used for teaching. The teacher adapts the way common knowledge (as well as abilities and social competences) is constructed to the pre-contents and *talents* of the pupils. The real outcome of the lesson is *not* a law of Newton but the *image* of this law in the mind of the student and his/her *command* in everyday use of this law. Obviously, the teacher must possess high competences not only in physics, but also in didactics, pedagogy, psychology, i.e. in all cognitive sciences. We say that the ratio between what the teacher knows and what is to be transmitted to the pupil is 9:1.

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[4] N. Chomsky, *Language and mind*, Cambridge 2006.

[5] G. Karwasz*, Czy świat się kręci w prawo? Fizyka i zabawki*, "Postępy Fizyki", no. 60B (1999); A. Okoniewska (Kamińska), *Przedmioty codziennego użytku i zabawki w dydaktyce fizyki – zjawiska falowe,* graduate thesis, Warsaw 1998.

[6] G. Karwasz, K. Służewski, A. Kamińska, *Constructivistic paths in teaching physics: from interactive experiments to step-by-step textbooks,* "Problems of Education in the 21st Century", vol. 64 (2015), pp. 6–23.

[7] G. Karwasz, A. Karbowski*, Hyper-konstruktywizm w nauczaniu fizyki. Tożsamość indywidualna i kompetencje społeczne*, "Acta Universitatis Nicolai Copernici Pedagogika", no. 36 (2016), pp. 177–202.

[8] G. Karwasz, *Cognitive Didactics: Hyper-Constructivistic Knowledge Building.* In: *Virtuality and Education – Future Prospects,* ed. D. Siemieniecka, Toruń 2019, pp. 9–22.

The difference with so-called social constructivism[9] is that the process of constructing the knowledge is strictly (but invisibly) guided by the teacher/university professor/a guide at the interactive exhibition. Therefore, classical principles of didactics, say, accessibility, practical applicability, visualisation, and active participation, are not abandoned but enhanced. No longer a direct, transmission-like teaching, a heuristic adventure involving the teacher and the pupils takes place: it is walking together step by step towards a well-defined (and usually hidden to the pupils) goal. This walking must also be well prepared for possible collateral paths. Physics, for several reasons, became the first playground for such hyper-constructivistic didactics.

2. Unwanted Physics

Physics in the "favourite" subject in school. This is not only so-called common thinking but is confirmed by comparative studies: in English elementary schools[10] an abrupt fall in interest can be observed between 3rd and 5th grades. In Europe, say The Netherlands, France, and Germany[11], the enrolment figures in engineering and science faculties dropped by 50% in the 1990s. Numerous methods and forms were proposed to induce the interest in physics: "Science on stage" organised by CERN, physics theatre[12] open to a broad public in Milan, and science centres in almost every mean-size city across Europe, Asia, and Aus-

[9] P. L. Berger, T. Luckmann, *The Social Construction of Reality. A Treatise in the Sociology of Knowledge*, Anchor Books, 1966.

[10] J. Osborne, *Attitudes towards science: A review of the literature and its implications,* "Int. J. Sci. Education", vol. 25, no. 9 (2003) pp. 1049–1079.

[11] M. Rocard, P. Csermely, D. Jorde, D. Lenzen, Walberg-Henriksson, Hemmo, *Science education now: A renewed pedagogy for the future of Europe*, European Commission, Directorate-General for Research Information and Communication Unit, Brussels 2007.

[12] Carpineti M., Cavallini G., Giliberti M., Ludwig N., Mazza C., Perini L. *Let's throw light on matter: A physics show for primary school,* "Il Nuovo Cimento", no. 121 B (2006), p. 901.

tralia[13]. These actions and/or centres bring a broader, general interest in science, but are not aimed at schools exclusively. For schools, a different approach is needed: a sequential narration, like in a book. Thus, numerous types of new textbooks are being experimented with.

These approaches range from Manga comics[14] that refer to sports activities, physical "circuses", i.e. exhaustive descriptions[15] of physical phenomena around us (but with few images) or university textbooks which are rich-illustrated and recalling everyday physical phenomena like *Conceptual Physics* by Paul Hewitt[16], which is now in its 15th edition. We compare (and discuss) these books in fig. 1.

However, this is not the number of illustrations or objects described but the very narrative approach[17], developed just at the dawn of cognitivism, which induces a long-life interest in science. The reader must be involved into constructing the knowledge.

3. Narrative physics: from practice to theory

In the previous paper[18] we described the main principles of innovative didactics, which were first experimented in educational practice and only later developed into a theoretical system. In our activities we started from interactive exhibitions in physics[19] before later developing other implementations, with various forms, target groups, contents and subjects.

Two principles lay at the basis of this innovative didactics: the first is constructing the knowledge together with the addressee (we call this hyper-constructivism), and the second is using real, touch-on objects

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[13] G. Karwasz, J. Kruk, *Idee i realizacje dydaktyki interaktywnej. Muzea i centra nauki*, Toruń 2011.

[14] H. Nitta, K. Takatsu, *The manga guide. Physics,* San Francisco 2009.

[15] J. Walker, *The flying circus of physics*, Wiley India Pvt., 2011.

[16] P. Hewitt, *Conceptual physics*, New York 1997.

[17] E.M. Rogers, *Physics for inquiring minds,* Oxford 1962.

[18] G. Karwasz, *Cognitive didactics*, op. cit.

[19] A. Kamińska, G. Karwasz, *Rola wystaw interaktywnych w nauczaniu fizyki,* „Fizyka w Szkole" (2008)

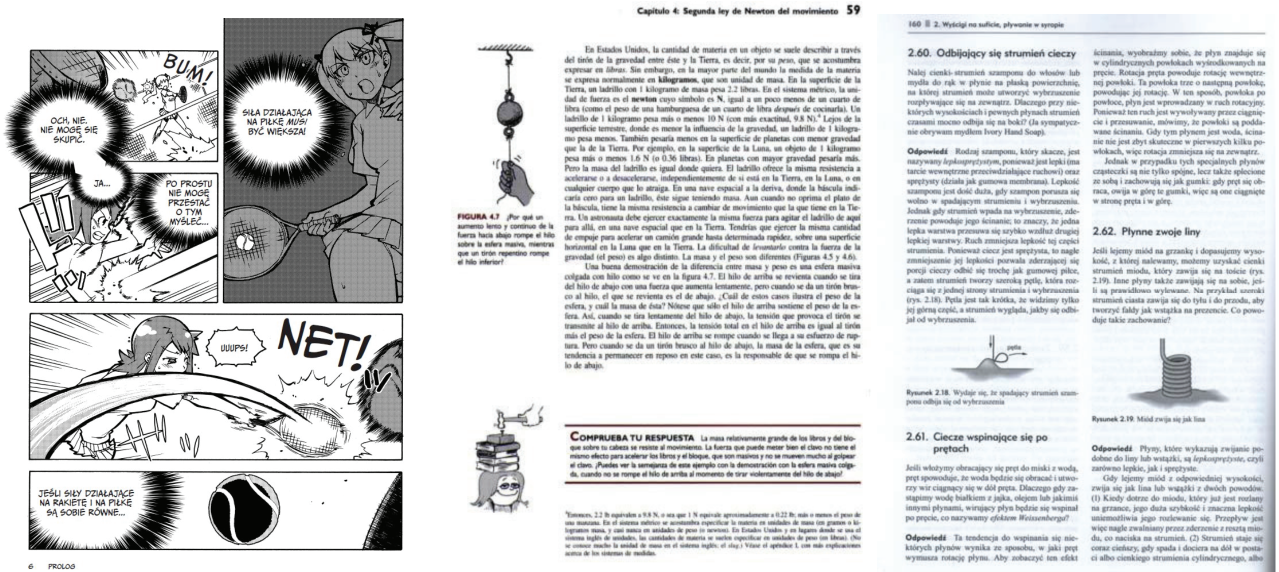

Fig. 1. Some alternative, new approaches to didactics of physics to increase the interest of pupils: (a) *The Manga Guide to Physics* – a comics book with a lot of drawings but didactically inducing wrong ideas – the rocket hiding the ball is not the best example to introduce the 3rd law of Newton; (b) *Conceptual Physics* by P. Hewitt, in spite of the promising title (and some 800 pages) is very much phenomenological – the two experiments shown here, with rapid and slow tiring the wire and with hitting a nail on a girl's head, are funny, but some mathematical formula should be given to explain the dynamics; (c) *The Flying Circus of Physics* by J. Walker on over 450 pages (Polish edition) describes a huge amount of experiments and physical phenomena, but not a single photo is given – a spiral of liquid honey is not like the one drawn here and you can try it at home.

(experiments in the case of physics, documents, books, and testimonies in the case of history). This second principle – of the return from the virtual world to real objects – is called neo-realism.

Here we describe some of applications of our constructivistic didactics in both national and international environments. We discuss various target groups (secondary school pupils, university students, teachers) and various forms: i) interactive exhibitions of simple objects "Physics and Toys"[20]) mixed poster, object and internet[21] exhibitions on modern physics, iii) interactive lessons for kids universities and secondary school students, and iv) narrative textbooks and books for children.

These different forms enhance various aspects of hyper-constructivistic didactics. Interactive exhibitions, for instance, primarily serve to draw attention and trigger the positive attitude but are not particularly systematic in terms of didactical narration. Interactive lessons allow us to keep the attention of the child/pupil/student from one cognitive step to the next but require an experienced teacher. Printed (and online) textbooks assure a broad diffusion and allow an individual velocity of the apprehension, according to the personal abilities of the reader.

4. Neo-realism: Physics and Toys

The concept of using simple, everyday objects to trigger interest in physics was established by Vittorio Zanetti at Trento University, more than 20 years ago[22]. He was first to realise that even in well-equipped Italian schools the practical understanding of physical phenomena was poor. For example, in elementary school we learn that by mixing so-called basic paints, other colours can be obtained. This knowledge remains at this elementary level even among adults: mixing red with yellow produces orange and mixing blue with yellow

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[20] G. Karwasz, A. Okoniewska (Kamińska), *Physics and Toys*, CD-Rom, Solion, Sopot 2004, see also: http://dydaktyka.fizyka.umk.pl/zabawki1

[21] G. Karwasz et al., *On the track of modern physics*, CD-Rom, Solion, Sopot 2005, see also: http://dydaktyka.fizyka.umk.pl/Physics_is_fun/

[22] V. Zanetti, *I giocattoli e la scienza*, "La fisica nella scuola", Vol. 4 (Oct-Dec 1993).

produces green. However colours on a TV screen are formed from green, red and blue, exclusively, and at the bottom of the carton box with milk (or juice) other colours – magenta, yellow and cyan – are printed. Basic colours in emission and in absorption are different. Vittorio Zanetti explained this at his interactive exhibitions by giving visitors colour filters and asking them to perform the synthesis of colours in an interactive way.

One of the authors (GK) worked as a guide at Zanetti's exhibition for the city of Trento starting from 1996. Subsequently, in 1998 some sixty objects were borrowed by Pomeranian University and showed during the II Science Festival in Warsaw (at the historical Potocki Palace) and in the Municipal House in Słupsk. Over four weeks, the exhibition brought in 14,000 visitors; according to the staff in Warsaw, people were queuing outside the building to see the event. We obtained our first constructivistic goal: to trigger the cognitive interest and positive emotions. The participation of an editor from Warsaw allowed us to publish the first, one-sentence descriptions of the objects (see fig. 2). They were very short but served as a starting point to *construct* the next exhibitions.

The role of simple objects in didactics of physics (and not only) is two-fold. On the one hand they trigger interest in physical phenomena: Why do two balls bounce to the left when I let two from the right fall? (fig. 3a). Do really heavy and light objects fall/roll down/slide down with the same "velocity"? (fig. 3b). Why does the needle of the voltmeter move when we touch two different metals? (fig. 3c).

On the other hand, objects serve to explain particularly difficult concepts. In the lesson about the laws of free fall we first show (or rather ask the audience to listen, without seeing) that a heavy, rubber ball and a light, ping-pong ball fall at the same time and then we perform the experiment with two carts on a inclined plane (fig. 3b); later, we drop two identical sheets of paper, but one squeezed into the form of a ball, and finally the same two rubber and ping-pong balls are dropped from the height of a ladder. In other words, this is not a single object but a whole line of didactical elements, threaded into a narrative string.

NIEBO I CZAS

1. Nieboskłon w parasolce
Gwiazdozbiory kręcą się nad głową

2. Niebo na piłce
Droga Mleczna na piłce plażowej

3. Gwiazdy w rurze
Konstelacje różnych pór roku obserwuje się w lunecie

4. Układ Słoneczny
Komputer analogowy wskazuje pozycje planet

5. Przenośny zegar słoneczny
Wystarczy skierować go na Gwiazdę Polarną

6. Zegarek pasterza
Pokrętłem ustawia się miesiąc, cień wskazuje godziny

7. Zegar w obręczy
Zegary słoneczne najdziwniejsze mają formy

8. Zegar w pudełku
Ten model „swatcha" pochodzi z XVI wieku

9. Klepsydra z piaskiem
Któż nie używa jej do gotowania jajek

10. Klepsydra na dwie ciecze
Spadające krople kolorowej cieczy mierzą sekundy

11. Zegar na metalowe kule
Kule spadające po równi odmierzają minuty

MECHANIKA

12. Ultradźwiękowy miernik odległości
Urządzenie to jest używane np. przez malarzy

13. Kieszonkowy surfing
Małe łódeczki walczą z burzą w szklance wody

14. Lampa kalejdoskop
Kiedy lampa świeci, kolorowe cekiny się wznoszą

15. Wańka-wstańka
Też jest urządzeniem fizycznym

16. Miś ekwilibrysta
Śmiało jeździ po linie

17. Cylinder na równi
Mimo przechyłu, cylinder nie zjeżdża?

18. Podwójny stożek
Ten dziwny oscypek podjeżdża po równi

19. Wahadło chaotyczne
Nie do przewidzenia są wahania kuli nad magnesem

20. Połamane wahadła
Kilka sztabek waha się jak „połamaniec"

21. Harmonograf
Kiedy stół się trzęsie, pisak kreśli dziwne krzywe

22. Piłka samoprzylepna
Piłka pełna przyssawek klei się do okien

23. Dwie piłki w spadku
Spadły razem, ale jedna z nich wraca pod sufit

24. Wahadło Newtona
Tyle ile kul uderzy, tyle ich odskoczy

25. Pracowity dzięcioł
Dzięcioł schodzi i pracowicie kuje

26. Piłka i suszarka
Piłka pingpongowa wisi w powietrzu

27. Wahadło Maxwella
Fizycy też się bawią yo-yo

28. Yo-yo
Energia nie znika

29. Pętla śmierci
Z jakiej wysokości zjeżdża motocyklista w cyrku?

30. Najkrótszy czas
Czasem warto iść po krzywej

31. Kolorowe bąki
Różne kolory można na nich składać

32. Pijany bąk
Ta dziwna cebula kręci się na głowie

33. Uparte czółenko
Celtycki amulet kręci się tylko w prawo

34. Żyro-kompas
Co wskazuje kierunek satelitom?

35. Lejek grawitacyjny
Gdzie kończą żywot gwiazdy?

TERMODYNAMIKA I CHEMIA

36. Termometr Galileusza
Kolorowe kule wypływają, jeśli jest im zimno

37. Miernik uczuć
Ciepło ręki wznosi ciecz w spirali

www.naszemiasto.pl
serwis informacji lokalnych

A to ciekawe

Dziennik Bałtycki · strony SŁONECZNE · 6 sierpnia 2004 piątek · ::29

Która bateria jest większa? Ta z prawej? A może jednak są takie same? Złudzenie otrzymano dzięki szklankom wypełnionym - bądź otoczonym - wodą, które działają jak soczewki.

To spragnione zwierzątko to nic innego, jak tylko dwa wypełnione cieczą naczynia unoszące się, bądź opadające pod jej wpływem.

Co by się stało, gdyby umieścito się metalowy długopis pomiędzy dwoma magnesami? Właśnie to, co widać na zdjęciu. Unosiłby się nad biurkiem!

Jeśli chcesz zmierzyć poziom własnej inteligencji przyłóż obie ręce do leżących na stoliku płytek i odczytaj wynik z elektrycznego wskaźnika.

Aby uzyskać światło z tej latarki nie potrzeba żadnych baterii. Należy jedynie szybko ściskać ją w dłoniach.

30:: · 6 sierpnia 2004 piątek · strony SŁONECZNE · Dziennik Bałtycki

Zabaw się z nami...

www.naszemiasto.pl
serwis informacji lokalnych

Lewitron - za tą skomplikowaną nazwą kryje się zabawka dająca wiele frajdy zwłaszcza odwiedzającym wystawę dzieciom. Dzięki magnetycznym właściwościom platformy i bąka może on lewitować.

Oto Wahadło Newtona - cztery stalowe kulki zawieszone na dwóch żyłkach nadające się nie tylko do zabawy, ale także do analizy zachowania energii i pędu.

Fizycy pokazali nam, że świetlówka przytknięta do kuli plazmowej... świeci!

Miłym akcentem wystawy jest lampka z obracającymi się dookoła żarówki kolorowymi rybkami, które podświetlone dają ciekawy efekt. Zawdzięczamy to zjawisku konwekcji, czyli unoszenia pod wpływem ciepła.

Każdy, kto choć raz próbował złapać tę sprytną świnkę na pewno poniósł porażkę. To nie dlatego, że jest ona super szybka, ale po prostu jest jedynie obrazem tej prawdziwej, znajdującej się wewnątrz naczynia.

Fig. 2. "Toys and Physics" interactive exhibitions: (a) 1998 in Warsaw at the Science Festival and Słupsk – laconic, one-sentence descriptions, (b) Sopot 2004 summer exhibitions – a mini catalogue published by the local journal*

* *Fizyka i zabawki*, „Głos Wybrzeża", 20.04.2004, https://nauka.trojmiasto.pl/Fizyka-i-zabawki-n11652.html

David Heywood and Joan Parker[23] express this idea in more complex wording:

> 'If in teaching science we are attempting to engage learners in activating and employing ideas that are incommensurate with existing frameworks, the we must necessarily, as part of instruction, provide appropriate *scaffoldings* to enable existing knowledge to be rationalised within the desired framework. This is particularly important pedagogical knowledge for primary teachers as they have the job of engaging young learners similarly in practice.'

Following these first successes, we received an invitation to present "Physics and Toys" at the National Congress of Physics in Białystok in 1999. For this event, some of the objects were bought directly by local organisers and pupils from secondary school in Białystok worked as guides for the visitors. We therefore obtained the second goal of starting the dissemination of the idea. In 2000 a real avalanche of interactive exhibitions in physics started in Poland.

One of the elements of such a fast divulgation was the "open-source" policy: we published the descriptions of all the "toys" on the internet. The number of exhibitions with physical "toys", smaller and larger, organised by associations, universities, or schools exploded after the first editions. As a result, we managed to identify the *social need* to make the physics more "appetitive". The simple toys became available on the Polish retail markets and therefore the most significant objects, like the "drinking bird", "walking ducks", "Celtic stone" and the slinky[24], became experiments used in many universities (Wrocław, Poznań, Szczecin, Łodź[25], nominating those known to us).

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[23] D. Heywood, J. Parker, *The pedagogy of physical science*, Spinger, Dordrecht 2010, p. 32.

[24] See: *Physics and toys,* http://dydaktyka.fizyka.umk.pl/zabawki1/index-en.html

[25] S. Bednarek, *Zabawki fizyczne – nowa generacja środków dydaktycznych do nauczania fizyki*" (Physical toys – a new generation of didactical objects for teaching physics) – lecture at XLI Congress of Polish Physical Society, Lublin 08.09.2011.

With portable exhibitions of physical "toys", physics became the first discipline that opened to a wide public. Soon, not only in Warsaw but practically in all university centres, science festivals started to be organised. This could be considered as a success but under a desired condition that over time the main charge of the permanent science divulgation would move to the professional centres and the university professors would act only as consultants/supervisors/lecturers. To our knowledge[26] of several centres in Poland, this is not the case: science centres suffer from a lack of backing from academic structures (and universities do not prepare specialists in science divulgation). As we wrote some time ago, the development has deviated towards phenomenology ('I have a nice object') as opposed to constructivistic teaching ('I want to show a physical law/ idea')[27].

The overwhelming success of phenomenology over the constructivistic narration was the main reason that we developed successive, pilot forms of cognitive didactics: 1) didactical tunnels ("Going downhill"), 2) thematic exhibitions ("Fiat Lux!, or playing with light"[28]), and 3) a series of interactive lectures in different subjects. We describe these implementations further on.

Albert Einstein said: 'Explain everything as simple as it is possible, but not simpler'. In answer, we would say: Dear Albert, you are the genius of the relativity theory, but the didactics is *our* field. We explain everything as simply as possible, and if necessary explain it in even simpler terms. This idea lay behind our next, well-aimed action, i.e. illustrating modern physics. This was done for the first time at the LVII National Congress of Polish Physicists in Gdańsk in 2003.

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[26] G. Karwasz, J. Kruk, op. cit.

[27] K. Służewski, G. Karwasz, *Fizyka i zabawki – wyjść poza fenomenologię. O żyroskopach, systemie słonecznym i momencie pędu*, "Physics in School", no. 3 (2014), pp. 25–32.

[28] See: G. Karwasz, *"Fiat Lux!" – czyli zabawy ze światłem,* "Postępy Fizyki", no. 4 (2010), pp. 154–158.

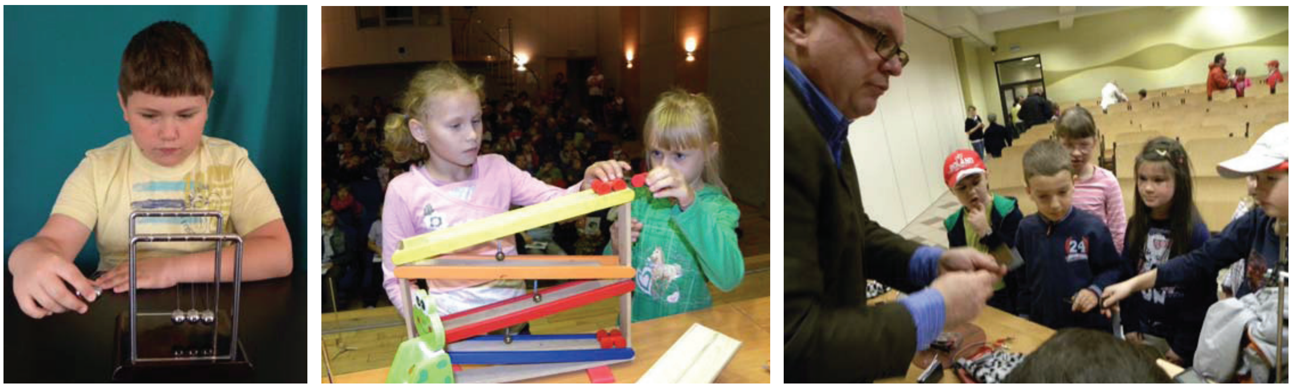

Fig. 3. Real objects involve the emotions of young students: (a) experimenting with Newton's cradle (Bartek Roszkowiak, 9 years old); (b) the racing on the slope with carts, light and heavy – UniKids lecture in Katowice, 2010; (c) Volta's pile constructed by pupils (and pairs of two different metals) – a spontaneously triggered experiment after the interactive lecture at Dąbrowa Górnicza, 2012. Photo: Maria Karwasz.

5. On the track of modern physics

In 2003, when we got pretty "tired" with simple interactive objects, i.e. toys, we decided to aim for a higher-level audience than children, i.e. students of physical faculties. The *rationale* for our interest in modern physics came from several separate observations: i) university students follow numerous lectures, but they lack any inter-disciplinary knowledge (and applications) of physics; ii) even professional researchers usually know only their own sector and lack broader expertise in other fields of physics; iii) access to the first-rank journals, like *Science* and *Nature* is, in Poland, quite limited (due to their high prices); and iv) the history of scientific discoveries is slowly disappearing – in the London Science Museum historical objects like the first vacuum diode or the first mass spectrometer of Aston has been removed to the highest level, less accessible[29].

All of these factors triggered a new type of interactive exhibition compared to "Physics and Toys" – not many objects with little text but extracts from scientific papers, drawings, pictures, and historical descriptions with few experimental examples[30]. The descriptions consisted of one-page stories explaining the history, importance, applications and open scientific problems. These *etiudes* are funny, at least at the surface level: the story about the scientific rush to discover new chemical elements via atomic collisions in great (and expensive) accelerators is entitled "Who gets to the island first?" (as the super-heavy elements were expected to form an "island of stability"). When introducing mass spectrometry we describe the analysis of the tiny remains of food left in Greek *situlas* 2700 year ago, probably the remains of King Midas' funeral feast.

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[29] G. Karwasz, J. Kruk, op. cit.

[30] G. Karwasz et al., *On the track of modern physics*, Toronto 2003, available at: http://dydaktyka.fizyka.umk.pl/Wystawy_archiwum/z_omegi/index-pl.html (access 15/11/2019)

Midas' funeral fest

Can we know what was eaten at a feast 3000 years ago? Yes, we can!

In 1999 archeologists discovered in Minor Asia, in land of ancient Frigia, a tomb full of precious objects of any kind, pearls, noble stones, expensive materials and subtle bronze dishes. The richness of the funeral indicated at high rank of the dead man, and place and age of the tomb pointed at similarity with ancient Greek cultures. Almost, almost king Midas' tomb.

On the bottom of bronze cups, in shape of sheep's head, there were some remains, almost unvisible with naked eye. The rests from the funeral feast? However, there was too little (and slightly out of date!) to taste it. But the appetite grows!

Luckily there is a contemporary science. It will tell you (and to the Police), not only how much you have drink but also what kind of alcohol! Different techniques used to find out what was eaten during the king's Midas funeral feast are common called **spectroscopy** (from Greek word *spectrum* it means a ghost).

It was a rich feast, that of Midas at his fineral: at the bottoms of the over 100 cups and plates the scientists found 16 different kinds of alcohols: a good quality wine, barley beer and fermented bee's honey. At the bottom of the dishes there were found at least 14 kinds of meat mainly sheep and goat. Meat first was grilled, and then detached from the bones, next mixed with Mediterranean herbs and spieces. Wines and beer were mixed in different proportions and served in elegant cups. Remains was loaded for king's Midas road through Styx river.

Well, well, such a funeral feast is enough to take a place in **mythology** forever!

Fig. 4. (a) Preparing the "On the Track of Modern Physics" exhibition in Gdańsk, September 2003. Speaking about the laser, we show the principles of its operation: semi-transparent mirrors (like in the "infinity tunnel" shown on the table), selective filters (like in some sunglasses), low-temperature plasma and so on. (b) "King Midas' funeral feast" – a short, funny inter-disciplinary story to attract attention to the didactical aim, which in this case is mass spectroscopy. http://dydaktyka.fizyka.umk.pl/Wystawy_archiwum/z_omegi/stypa-en.html

The idea of un-bronzed presentation of modern physics became so attractive that in 2005 we were awarded the EU Science & Society Programme, which we named "Physics is Fun". The collection of didactical posters, web descriptions, updated stories and real objects shown during exhibitions in Lubljana, Warsaw, Paris, Trento and Berlin were collectively titled "On the Track of Modern Physics". As an outcome of the project all the didactical material was uploaded to the web: our pages http://dydaktyka.fizyka.umk.pl gain some 200,000 hits each year. In principle, the page is still vivid as we planned to publish new descriptions every two weeks.

Although the "Physics is Fun" project is dated from 2005–2006, the idea of treating physical discoveries with some irony recently gained a broader public. A gastronomy web-page *Gastro Obscura*[31] (that "covers the world's most wondrous food and drink") and the internet edition of *Time*[32] recently described Midas' funeral dinner as one of the top ten feasts of all time: physics is widely cited there and the topic, identified by us, is of a wide, inter-disciplinary interest.

The main principle of our hyper-constructivistic didactics implemented in "Physics is fun" is interlinking with other sectors, including archaeology, geography, mythology, food sciences and cooking. We have further developed such stories in papers in "Chemistry in School", "Geography in School"[33], "Polonistyka", etc. We refer the reader to those texts.

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[31] A. Ewbank, *Recreating King Midas's 2,700-year-old feast*, "Gastro Obscura", 11.12.2017, https://www.atlasobscura.com/articles/king-midas-feast-recreation-tomb (access 15/12/2019)

[32] I. Tharoor, *King Midas's funeral banquet*, "Top 10 Feasts", "Time" 25.11.2010, http://content.time.com/time/specials/packages/article/0,28804,2033096_2033097_2033186,00.html (access 15/12/2019)

[33] See: G. Karwasz, *Między Scyllą a Charybdą*, "Geografia w szkole", 2013; G. Karwasz, *Rubiny, złote szkło i brazylijskie motyle, czyli o kolorach w fizyce, chemii i biologii*, "Chemia w szkole", no. 3 (2012), p. 5.

6. "Going downhill"

The thematic exhibition with a fairly long title "Going downhill, or everything on the inclined plane of Galileo, in other words, how the potential energy changes into the kinetic one and how one can have much fun with this" was born as an answer to a long-standing didactical problem. The inclined plane of Galileo was of an essential importance for the birth of physics. Indeed, it was said that 'Physics descended from heavens to earth on the inclined plane of Galileo'[34]. Its valence lies in the fact that this is the simplest (and most adjustable) verification of the laws of accelerated motion (comprising the free fall): a starting point for Newton's laws.

However, in the dull, school teaching environment, the decomposition of the gravitational force along the inclined plane became a "mental torture" for pupils ("one force is sine and another cosine, but who remembers which?"). The pleasure of studying physics disappears in the very first lessons. How can one use the interactive objects collected for "fun" in a real, didactical and systematic, school-like narration?

We decided to introduce complementary and different aspects of the inclined plane – rolling, strolling, sliding, jumping downhill step by step, etc., using amusing objects but ordered into a precise didactical path. Descriptions became even more laconic than in the first edition of "toys": "Going downhill – by steps", "Going downhill – sliding ", etc. The lack of instructions did not prevent the public from engaging enthusiastically as the objects were self-explaining (see fig. 5).

The objects were ordered "by steps" not only to introduce different aspects of kinematics but also with rising difficulty. A clear but hidden didactical objective was to teach the laws of the uniform and accelerated motion and the three principles of conservation – energy, momentum, angular momentum. Altogether, we collected some forty objects.

In the last experiment, two guides demonstrate the relativity of the motion, i.e. the crucial passage from Galileo's to Einstein physics. We go beyond simple playing and pose important scientific questions

[34] E.M. Rogers, op. cit.

Fig. 5. The “Going downhill” interactive exhibition organised inside a inside a corridor at the Institute of Physics, UMK, April 2007. Objects on sliding, falling, and rolling down are organised in a sequence of rising difficulty. Very laconic, one sentence explanations are on the tables, and detailed descriptions for teachers are provided on the reverse of the sheets. As seen in the picture, children not only understood the experiments but also exchanged explanations. (b) A separate room was reserved for children at pre-school age: just playing (but with new tasks) is also didactics as it induces creativity, active participation, appropriate *ad hoc* group collaboration, etc. http://dydaktyka.fizyka.umk.pl/pazurki/galileo.html. Concepts, descriptions, objects (C) GK, photo: K. Służewski

to stimulate a post-exhibition reflection among the visitors. This activity completes the goals or our didactics; as said by Polish author Z. Pietrasiński, 'Thinking is a condition for learning but also it's the most important outcome'[35].

In 2007's "Going downhill", the main stress was on didactics even if it was hidden behind play. In our earlier exhibition, organised in the summer of 2004, in Sopot, under a title borrowed from a song "During rain children are bored", the main stress was simply on children *playing* with parents. The need for fun ("ludic" activities) in education has been noticed not only by us; Comenius, for example, postulated that 'school became as pleasant and interesting for pupils as a funny fair'. Recently, even in traditional museums the need for ludic activities has been recognised. Sarah Campbell, curator of exhibitions from University of the Arts, London, has written[36] on these activities (and on real objects to be handed to students):

> 'Handling museum objects can give students a tangible level of excitement and allow them to glean information from objects first-hand. The trust we place in them also makes this teaching experience special and different to many of the other interactions they will have. Through ludic practice, games and play will feed into and support this engagement with objects as well as offering new types of interaction.'

However, as previously stressed[37], the ludic function of the exhibition/lecture/object is just one of the three complementary functions: didactical ↔ ludic ↔ scientific. Only when all three functions used together can we fulfil the cognitive expectations of a broad public – from children through teachers to university staff.

Therefore, in the first exhibition in Toruń, apart from the enthusiasm of the young public (see again figs. 5), we were able to trigger the interest of the university staff at the UMK Faculty of Physics, which

[35] Z. Pietrasiński, *Sztuka uczenia się*, Warszawa 1975.

[36] S. Campbell, *Ludic practice: the case for students play in university museums. Spark: UAL Creative,* "Teaching and Learning Journal", vol. 4, no. 1 (2019), pp. 59–70.

[37] G. Karwasz, J. Kruk, op. cit.

later led to the construction of the science centre. Moreover, Galileo's concept of the free fall was further used in an almost infinite series of interactive lectures on the laws of mechanics for children, pupils, students, and teachers, both in Poland and abroad. Almost identical contents and the same hyper-constructivistic steps assumed a different narrative form.

7. Hyper-constructivistic lectures

By developing successively different forms of interactive didactics, we managed, to some extent in an evolutionary way, to implement several principles of our new, cognitive didactics:

1) "Physics and Toys" provided a resurgence of real objects in the times of rapidly growing virtuality and invited the visitors to take part in unlimited experimental activity;
2) "Going downhill" introduced a step-by-step walking in the cognitive "tunnel";
3) "Modern Physics" used elements of the history of physics, its current implementations and inter-disciplinary aspects.

Nonetheless, we still lacked the immediate and direct feedback from the kids/pupils/students/adults in order to control the correct building of the knowledge in the desired direction. This goal was achieved through the significant number[38] (some 300) of interactive lectures produced for all audiences.

The principle of the lessons, in all subjects of physics and astronomy, is that almost the same contents can be transmitted (or better: constructed with the audience) regardless of their age: what differs from audience to audience is the type of narration and the vocabulary used. The most difficult task in this type of didactics is to keep the attention of the *entire* audience during the whole lesson (45–60 minutes) (see fig. 6a) and to manage technically with quite complex experiments while keeping the narration (see fig. 6b).

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[38] For a list (non-complete) of lectures by GK, see http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/572

Fig. 6. "Why do objects fall?" – an interactive lecture (GK) for secondary-school teachers at the University of Macerata, Italy, 2014; (b) explaining and performing experiments is a difficult task – a lesson (AK) on energy, environment and hydrogen technologies at IX Liceum in Gdynia (2019). Photo: Maria Karwasz, Tadeusz Bury.

The main achievement is that spontaneous activity of the public is triggered and sometimes almost impossible to restrain. In this way, however, we can also implement the principles postulated elsewhere[39]: the individual visibility (and responsibility) of the pupil, a sane competition, and self-corrections – a feature which has been lost in the recently developed educational system in Poland. In addition, surprisingly, the less experienced the audience, the more interesting the collective construction of the knowledge becomes. Unfortunately, hyper-constructivistic lectures require a teacher who is experiecend not only in the scientific subject but in everything that Lee Shulman in 1987 called "Pedagogical Content Knowledge"[40]: looking into the eyes of the pupils and trying to understand what *they* have understood.

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[39] G.P. Karwasz, A. Karbowski, *Hyper-konstruktywizm w nauczaniu fizyki. Tożsamość indywidualna i kompetencje społeczne*., "Acta Universitatis Nicolai Copernici Pedagogika", no. 36 (2016), pp. 177–202.

[40] L.S. Shulman, *Knowledge and teaching: Foundations of the new reform*, Harvard Educational Review, vol. 57, no. 1. (Feb 1987), pp. 1–21.

8. Hyper-constructivistic textbooks

The interactive exhibitions, as already said, have been developed with a better or worse success in many places in Poland; the cognitive lessons have also found many followers with kids universities flourishing in almost every mid-size town in Poland[41]. However, in order to document our constructivistic approach we also need to highlight a new type of textbook which is markedly different to that shown in fig. 1. At the school level we call them "tex-boooks" (in Polish "po-ręczniki" instead of "podręczniki", which need to be approved by the Ministry).

In the books we adopt the same principles as in our other forms of teaching: the reader must be sure that the knowledge he or she is going to acquire is (already "is", not "will be") useful. Further, the reader must be convinced that the book only *guides* his/her own reasoning. In the book introducing physics[42] (previously the 1st class of junior high school, now the 7th class of primary school), instead of listing the mathematical prefixes (kilo, mega, etc.) we show objects that use these denominations: small electrical capacitors (pico, nano, farad), small water turbines (megawatt), and nuclear electric plants (gigawatts). Using the principle of realism there are no drawings but photos, with places and dates (see fig. 7a).

In *Astronomy for Children*, the editor (she, Polish, graduated in humanistic sciences) expected that the book would start with a list of astronomical objects and with the explanation that the sun is not walking on the firmament but rather the Earth is orbiting the sun as discovered by Copernicus (who was Polish). Just the beginning and the end of the book: no place for a heuristic, step-by-step discovery of the limits of the universe and admiration for the vivacity of the life of stars (as stated by Aristotle in his *De coeli*). Therefore, our *Astronomy for Children*[43] starts

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[41] A. Wieliczek, E. Lewicka-Kalka, P. Ziółkowski, *Uniwersytet (dla) dzieci. Wokół teorii i praktyki*, "Zagadnienia Naukoznawstwa", no. 3/213 (2017), pp. 343–361.

[42] G. Karwasz, M. Sadowska, K. Rochowicz, *Toruński poręcznik do fizyki. I Mechanika*, Toruń 2010.

[43] G. Karwasz, *Astronomia dla dzieci*, Poznań 2016.

2.5 Przedrostki jednostek pomiaru

Jak już na pewno zauważyłeś, bardzo rzadko korzystamy z podstawowej jednostki fizycznej takiej jak metr. Do pomiarów odległości między miastami używamy *kilo*-metra. Wzrost podajemy w *centy*-metrach, a grubość wkładu do ołówka w *mili*-metrach. Używamy więc *przedrostków*. Przedrostki te pochodzą z języka greckiego. Na przykład „centy" oznacza część setną. W tabeli poniżej podajemy znaczenie i skróty najczęściej używanych przedrostków. Wytłuszczoną czcionką podajemy te najważniejsze.

Wielokrotności „10"

mnożnik	nazwa	skrót	przykład
10	deka	d	dekagram=10 g
100	hekto	h	hektolitr =100 litrów; 1 hektar = 100 arów = 100x100 m^2
1000	**kilo**	**k**	**kilogram = 1000 gramów; kilometr = 1000 m**
1 000 000	**mega**	**M**	**megawat (moc turbiny elektrowni) = 1 000 000 W**
1 000 000 000	giga	G	gigawat (moc elektrowni atomowej) = 1 000 000 000 W
1 000 000 000 000	tera	T	10 terawat (elektrownie świata) = 10 000 000 000 000 W

I tak, *moc* kuchenki elektrycznej to 1 kilowat, moc małej turbiny wodnej to 1 megawat (tysiąc razy więcej) a moc elektrowni atomowej to 1 gigawat (moc tysiąca małych turbin wodnych).

Ułamki „10"

mnożnik	nazwa	skrót	przykład
0,1	decy	dc	1 decymetr = 0,1 m = 10 cm; 1 dm^3 = 1 litr
0,01	**centy**	**c**	**1 centymetr = 0,01 m = 10 mm**
0,001	**mili**	**m**	**1 milimetr = 0,001 m; mililitr = 0,001 litra = 1 cm^3**
0,000 001	**mikro**	**µ**	**1 mikrometr („mikron") = 0,001 mm; włos = 50 µm**
0,000 000 001	nano	n	0,1 nanonometra = typowe rozmiary atomu
0,000 000 000 001	pico	p	picofarad = pojemność elektryczna małego kondensatora
10^{-18}	atto	a	attosekunda = czas przeskoku elektronu w atomie

Każdy kraj nieco inaczej używa przedrostków jednostek miar. I tak w Polsce kupuje się mięso na „deko", czyli dekagramy, we Włoszech na „etto", czyli hektogramy. Włoskie dwa „ettti" to polskie 20 „deka" a właściwie (w systemie międzynarodowym) 0,2 kg. Pojemność butelek z winem Włosi podają w mililitrach (750 ml), Polacy w litrach (0,75 litra) a Francuzi w centylitrach (75 cl). I tak znajomość fizyki może się przydać w restauracji za granicą!

Fot. 2.6 Przedrostki jednostek miar pozwalają w skrótowy sposób charakteryzować szeroki zakres wielkości fizycznych a) „pojemność" kondensatorów zmienia się od *piko* przez *nano* do *mikro*; b) moc małej turbiny wodnej (wysokości człowieka) to 1 MW; c) moc jednego reaktora w elektrowni atomowej to typowo 1 GW.

Mały Wóz

Gdzie zobaczysz gwiazdy

Aby oglądać gwiazdy, nie trzeba udawać się w specjalne miejsce. Najjaśniejsze z nich widać nawet w zadymionym mieście. Jednak by naprawdę podziwiać rozgwieżdżone niebo, warto wyjechać gdzieś dalej: w góry, nad jezioro, może nawet na pustynię, gdzie nic nie zakłóci obserwacji.

Wielki Wóz

Namów rodziców...

Gwiazdy są bardzo daleko – ich światło, które oglądamy, podróżowało do nas dziesiątki, setki, a czasem miliony lat. Aż dziw, że ludzkie oko je widzi. Jednak nie ta odległość jest główną przeszkodą, ale zakłócenia, jakie wytwarza sam człowiek. W wielkich miastach, a nawet mniejszych miejscowościach, jest tak wiele latarni ulicznych, że trudno zobaczyć gwiazdy.
Aby je dostrzec, nasze oko musi najpierw przyzwyczaić się do ciemności. Zajmuje to 20 minut.

Niebo najlepiej oglądać w zupełnym mroku. Namów rodziców, abyście latem wyjechali nad jezioro, gdzie nie ma lamp ani świateł domów. W ciepłą noc połóż się na kocu i spójrz na niebo. Zaczynamy naszą astronomiczną przygodę!

Wielki Wóz

Najpierw popatrz na północ, czyli tam, gdzie nigdy nie świeci Słońce. Siedem gwiazd, ułożonych jak wóz z czterema kołami i dyszlem po lewej stronie, tworzy **Wielki Wóz**. Nad nimi znajduje się **Mały Wóz**, też złożony z siedmiu gwiazd. Wyciągnij przed siebie rękę, rozstaw palce i zmierz odległość między tylnymi kołami Wielkiego Wozu. A teraz popatrz w górę, ponad jego tylne koła – pięć odległości nad nimi znajdziesz inny jasny obiekt: to **Gwiazda Polarna**, która wskazuje drogę żeglarzom. Niebo, a wraz z nim wszystkie gwiazdy, cały czas kręci się nad głową. Tylko Gwiazda Polarna nie zmienia położenia.

14 Scienza e Fede

Creare il mondo?
1. Sole
2. Terra
3. Albero
4. Casa
5. Uomo
6. Nuvola

Figura 1.1. Uno scherzo intellettuale: come progettare il mondo?
La sequenza che propongono tutti, indipendentamente dalla lingua, età, educazione è sempre la stessa: prima il sole e la terra, coma suggerisce "la ragion comune" e non l'idrogeno e le stelle, come dice la fisica.
FONTE: Autore

Per capire come è stato l'inizio del mondo secondo la scienza moderna dovremo prima comprendere qualche principio di fisica, chimica, cosmologia. Ma per non fare i "sapientoni" ricordiamo che le domande sull'universo fanno parte della cultura umana in senso ampio, dalla filosofia (metafisica) alla teologia, dalle arti visive alla letteratura, fino all'astrofisica. La stessa domanda è stata esaminata e interpretata nella storia in modi molto diversi. Qui sotto sono riportate due immagini di Dio creatore: una meno nota, medievale, della cattedrale normanna di Monreale, un'altra ben conosciuta, rinascimentale, della Cappella Sistina.

Figura 1.2. Due immagini della creazione del mondo: sull'affresco della Cattedrale a Monreale, Dio giovane, sorridente (e con una pianta in mano) sta plasmando i pianeti; secondo Michelangelo Dio somiglia a Zeus, con tanto di gesti fulminanti.

FONTE: Duomo Monreale, Foto © Ulrtreya, Milano; Cappella Sistina, Foto © Musei Vaticani, con gentile concessione.

Fig. 7. Neo-realism and hyper-constructivism in books: (a) "Mechanics", for 1st class of junior high school: mathematical prefixes exist in real objects such as electrical capacitors, hydro turbines, and electric power stations. (b) "Astronomy for children" is a heuristic adventure: lay down on a blanket and look at the sky. (c) Make your own Universe: first Sun? or separating light from darkness (the drawing by GK) and compare it with more renowned artists from Monreale (13th century) and Rome (17th century), and with modern cosmology.

with 'When you are on holiday [no stars are visible with city lights] on a lake [not in a forest], lay down comfortably on a blanket [not to get cold] and look at the sky. Note the stars, and check an hour later – where there are now? Yes! the whole firmament rotates above your head'[44].

It is not only physics that requires a hyper-constructivistic approach. Simple, but politically difficult issues like climate change cannot be argued if the interlocutor does not make a full, iterative and sometimes contradictory reasoning; he/she needs to remain astonished by the result at which she/he has arrived. In-between "Science and Faith",[45] we ask: 'A Big Bang or the Creation? Try to make you own reasoning: compare the Bible and modern physics. Make your own drawing'. Regardless of the audience this drawing is always similar to that presented in fig. 7c. Why? It is the point at which constructivistic narration starts…

9. Conclusions

The constructivistic didactics of physics in Poland in 1998 were imported from Italy, rapidly developed into a myriad of implementations: itinerating and stationary interactive exhibitions, science centres, virtual exhibitions, interactive lectures, and constructivistic textbooks.

As a quantitative measure of this success, we recall the "Hevelianus" Science Centre in Gdańsk, which opened in 2009, and the 1,000,000 visitors at the "Kopernik" Science Centre in Warsaw during its first year of activity (2011). The reasons are three-fold: the first was the lack of interactive didactical forms and methods in Poland before 1998 – in the USA, Germany, and France science centres and museums were established starting from the late 1960s[46]. The second reason is the edu-

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[44] This is a very important statement, as already noted by Copernicus, anyone who says that Earth would disintegrate because of its rotation should explain why the whole, immensely great (and of unknown dimensions) ceiling does not go into pieces. Didactically, even in Toruń nobody remembers what is written on Copernicus's monument: "Terrae motor, Solis *Caelioque* stator."

[45] G. Karwasz, *Scienza e Fede. Un breve manuale*, Roma 2019.

[46] See G. Karwasz, J. Kruk, op. cit.

cational demand: Polish teachers, in the OECD Report issued in 2009, declared the *will* to use constructivistic methods to a much greater extent than, say, Italian teachers[47]. However, as diagnosed at the same time, the absence of constructivistic *practices* in school was the reason for the relatively low performance of Polish students in reading and understanding OECD PISA tests[48].

Nonetheless, the success of our hyper-constructivistic lectures, exhibitions and internet pages is not limited to Poland. As described with more details on our web pages, we have also practiced our innovative forms of didactics in France, Italy, Germany and Korea[49].

The variety of forms and the continuous demand for lectures and exhibitions makes detailed studies of the educational outcome difficult: this should be done not by the authors but the external observers. Regardless, the facts, i.e. the enormous success of interactive exhibitions in physics in Poland, speak for themselves; we are rather missing some exhibitions on arts, humanities, philosophy, history, etc.

Concluding, rapidly changing information technologies and educational difficulties in schools (not only in Poland) still require innovative approaches and a wide divulgation of successive methodologies. The subject of innovative didactics needs further studies.

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[47] *Creating effective teaching and learning environments: First results from TALIS*, OECD, 2009, p. 95. Polish teachers declare rather constructivistic beliefs over direct transmission beliefs, and are in the middle of the classification between Iceland and Austria (the highest ipsative means towards constructivism), with Malaysia and Italy at the other end.

[48] M. Wiśniewska-Kin, *Szkoła zapytująca miejscem rozwijania dziecięcych sposobów rozumienia*. In: *Dokąd zmierza polska szkoła?* ed. D. Klus-Stańska, Warszawa 2008.

[49] *Professor G. Karwasz teaches in Korea*, http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/586

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