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Ten years of the project Chain Experiment

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Abstract

In this paper the project Chain Experiment is presented. It can be viewed as a competition or as a popularization activity for science, technology, and physics in particular. We present the basic idea of a toppling-domino-like chain of contraptions that are operated one after another, and each demonstrates different physical phenomena. The evolution into its current form with three different types of activities is briefly described. The emphasis of the paper is on the impact of the project on physics education. The ways in which physics students, physics teachers, and participating pupils profit from the different project activities are presented in detail.

Keywords: Chain Experiment, physics competition, popularisation of science, physics education

(Some figures may appear in colour only in the online journal)

Introduction

The project Chain Experiment started in 2004 as one of the activities to celebrate the World Year of Physics 2005 and became one of the most noticed activities in Slovenia. The project is organised with the cooperation of the University of Ljubljana, Faculty of Education [1], The Society of Mathematicians, Physicists and Astronomers of Slovenia [2], and the Technical Museum of Slovenia [3]. The initial objective of the project in 2004 was the construction of a promotional demo chain experiment to bring physics closer to people and to motivate people to participate in the first national competition in May 2005. The demo chain shows also served as a demonstration of how the contraptions are connected in a chain and how to build contraptions—future parts of the long chain at the national competition. Because of the very good acceptance by diverse target groups it was decided to continue with the project and make this national competition an annual event.

Since then the project has evolved into three activities: demo chain experiment exhibitions [4], annual national competition and show [5], and team building events [6]. Each of the

Figure 1. Logo of the Chain Experiment project in Slovene (left) and English (right). Reproduced with permission from Jurij Bajc.

three activities is a variation of the same basic idea—a chain of contraptions. However, the focus of each activity is different, addressing different target groups with different objectives. The three activities are in a way complementary. The main objective of the demo chain experiment consisting of ten contraptions is promoting physics and technology, demonstrating the main idea of the chain experiment, and encouraging people to build their own contraptions for the national competition. The national competition gathers diverse groups of constructors, ranging from kindergarten children to students and adults, to show their contraptions and to compete for different types of awards. The third activity is a team building event for participants from various walks of life. The task of the participants is to figure out how the contraptions work and to link them in an operational chain.

The chain experiment consists of mechanical contraptions that are put into motion in a sequence—resembling the well-known toppling rows of dominoes, but using the metal sphere as a linking element as indicated by the project logo (figure 1). There are two basic concepts that are followed in constructing a contraption—it should be based on an interesting physical phenomena and it should be self-operating, i.e., after it has been triggered all the action in a contraption should be performed without any intervention by the constructors [5].

After the successful first run in 2005 the Chain Experiment has now become part of extracurricular education nationwide in Slovenia and is attracting attention in Europe. The project has been presented at several international conferences and meetings, such as GIREP (2005), GIREP-EPEC (2007), ShowPhysics (2006, 2009, 2011), ShowScience (2015) and at local conferences and physics shows [7–11]. In 2014 our Polish colleagues have started a chain experiment competition taking the Slovenian project as a model [12].

Although the project targets audiences of all ages, the main focus is on younger generations from preschool children to students. The project represents an example of good practice in promoting science and an alternative way of teaching. Besides the obvious relation to physics and technology, the project objectives are also to develop practical skills, design, communication, and team work. In this contribution the main aspects of the Chain Experiment project, its importance and benefits in the field of education, and the historical overview are presented, having in mind in particular the teachers of physics, science, and technology at all levels of education.

The evolution of the project

In a decade of existence, a variety of positive consequences of the project have emerged. They are closely related to the conceptual development of the Chain Experiment. One of the byproducts is a strong and fruitful cooperation between different institutions. The project was launched by the Society of Mathematicians, Physicists and Astronomers of Slovenia in close collaboration with Faculty of Mathematics and Physics at University of Ljubljana. Driven by

Figure 2. Demo chain experiment in one of the malls of Ljubljana, attracting lots of random bystanders.

the World Year of Physics 2005 agenda the main objective of the project was to promote physics in Slovenia. For this purpose the faculties that educate future physics teachers and physicists encouraged their students to participate in the development of the demo chain contraptions. As a part of the course Project Laboratory 1 at the Faculty of Mathematics and Physics, physics students were, for example, given very specific instructions on how to transmit action from one contraption to another, forming a very interesting chain of four contraptions. The first contraption had to be set in motion by pouring half a litre of water into a container and had to end by a flash of a light emitting diode. The second one had to be triggered by the flash of light from the first one and had to end by inflating a balloon [13]. The third one had to start by some interaction with the inflating balloon and had to end with a whistle that had to trigger the fourth and last contraption in the series [14]. From a popularisation point of view, such a demo chain was perfect, but the goal was also to construct a nationwide movement of making contraptions in schools and by interested individuals in order to make a big science popularisation show, based on a long chain experiment. To not only fascinate a general audience, but also to motivate people to actively participate, the second part of the demo chain was constructed. This time future physics teachers and physics students at two faculties of education were recruited. Their task was to construct contraptions according to the standardized rules that are still used in the contemporary national competition with very subtle modifications. The additional six contraptions not only illustrated well the use of a standardized linking steel spherical ball, but also how interesting physics can be demonstrated by ingenious yet simple mechanical devices, such as a scale, a spinning top, or pendulums and springs [4, 15–17]. The contemporary rules and hints are described in a separate section.

Encouraged by the success of the first Chain Experiment in May 2005, but also knowing that the enthusiasm inspired by the World Year of Physics would probably not continue in the succeeding years, the national competition has been organized as an annual event ever since. This has slightly altered the structure of the participants. It turns out that a contraption building competition results in higher participation of established educational institutions, for example schools. Most teams taking part are from primary schools, whereas teams from kindergartens and high schools are always present, but in smaller number. Over the years, a certain pattern related to mentors is noticeable. Very often a teacher who has a team of constructors one year returns the next year with one or even with several teams and becomes a regular team mentor. This pattern goes hand in hand with the altered character of the event—

Figure 3. Satisfied participants of the team building event in Orehov gaj near Ljubljana.

the annual competition is considered the final act of the whole year-long extracurricular activities that are organised in some schools especially to build the contraptions. Depending on whether a particular teacher finds the whole process of constructing, making, testing, and improving a contraption worth his or her efforts the school participates or not. More about the educational side of the contraption making is given in the following sections. In any case, learning physics while experimenting and gaining additional technical, communicational, and group working skills are the benefits of the Chain Experiment project.

At present the demo chain experiment supports the annual competition in an even more varied way than at the beginning (figure 2). It also serves as a teaching aid to facilitate learning physics, particularly in primary schools, where it is executed in the form of a workshop. Running the demo chain experiment in public places such as museums, malls, or fairs presents a unique way of addressing the most general audience and thereby increasing their awareness of science. Each year around 10–15 workshops in schools and exhibitions in public places are organised all over Slovenia.

As the final evolutionary state of the project, the use of the demo chain contraptions in team building events has been developed during the last few years in cooperation with the company Team Building Lab. It turns out that setting up the already-made contraptions into an operational chain is more than suitable for enhancing the team spirit of the staff in a small

company or a department of a larger enterprise [18]. The idea is straightforward, yet extremely efficient in its simplicity. Participants are grouped in teams of 3 to 6 and every team has to figure out how their contraption works, to prepare the contraption for operation, and to link it with the preceding and the succeeding contraption. The main objective of the activity is to mimic the processes in a company: the importance of every constituent, the cooperation and communication among the groups, the team spirit in a group, etc. From a project point of view the engagement in the team building activities provides an additional way to promote physics in a completely different social group of people. Adult participants come to team building events to have fun. The relaxed atmosphere and common goal to put the chain in operation provide excellent conditions to (re)learn some elementary physics and to leave the event with a smile on their faces and with a positive attitude towards science in general (figure 3). Each year around 10 team building events are organised.

After this short arc of evolution of the project the particular features and their educational relevance are described in the following sections. However, the details of how the contraptions are prepared in order to make a chain operational are described first.

Ideas and regulations for designing contraptions

The initial idea of constructing a chain of contraptions was taken from the *Friday After Thanksgiving Chain Reaction* event, which has been organised annually since 1998 at Massachusetts Institute of Technology (MIT) in the USA [19]. In the Chain Reaction the contraptions are designed fairly at will with only a few restrictions related to size and safety. Each contraption is linked to the next one by a string—a pull of the string triggers each contraption. In the Slovenian version of the project we kept the freedom of building creative contraptions, but also require the inclusion of interesting physical phenomena in particular. The last requirement has a rather important consequence—it helps to make the whole construction of a contraption more content oriented and more educational. When applying for the national competition, members of the team have to prepare a short description of the operation of the contraption. Within the description there should be explanations of physics related to the operation of the contraption, so the constructors have to think about the physics in their contraption and collaterally they learn in a more goal oriented and therefore playful way. We slightly modified the rules related to the dimensions, so the contraptions fit on a standard school desk (120 cm $\times$ 60 cm), and can be a bit higher than those in the MIT Chain Reaction. Safety restrictions prohibit dangerous chemicals, open fire, high voltage (above 24 V) and use of animals. Another important characteristic of the contraption is the time of operation and its repeatability—it should be active for at least 20 s, but not more than 2 min, and it should easily be reset to the initial state. The last requirement is important in order to repeat the run of the chain in a reasonable time.

The most important difference between the Chain Experiment and the Chain Reaction at MIT is the linking element. Although a linking string used at MIT provides a lot of freedom in arranging contraptions in a chain, the force by which the string is pulled is relatively difficult to predict and to control. This might pose a problem with triggering a successive contraption and may thereby stop the chain's operation. The Chain Experiment being a competition, and the performance of a contraption one of the evaluation criteria, it is evident that the linking of the contraptions should be unambiguously defined. The experience with the demo chain experiment in the academic year 2004/2005 empirically confirmed the necessity of a well defined triggering of a contraption. The free fall of the steel ball with a 2 cm diameter from a height 45 cm above the base of the contraption has been selected as a trigger to start the action of a contraption. Accordingly, a contraption's action has to end by releasing

the linking steel ball from a height 45 cm above the base. The latter need not be the same ball that triggered the contraption, but it has to be dropped from the prescribed height. Although this seems to be a reasonably well defined linking rule and in general works fine in most cases, the last additional hints that improve the linkage ability of the contraptions have been added in 2016. The described linkage between the contraptions enables the constructors to easily adjust the triggering and the ending of their contraptions, as all of them receive two linking steel balls after applying to participate in the Chain Experiment national competition. The selection of the steel ball as a linking element has another advantage. During the free fall the ball gains a considerable momentum and is thus able to move an object and trigger a contraption mechanically. On the other hand a steel ball is an electric conductor and can be used as a switch in an electric circuit. A single linking element can therefore trigger a contraption in various ways giving the constructors even more space for creativity and diversity in building contraptions.

National competition

The annual national competition is where the constructors present the results of their work done throughout the school year. It is also an exhibition and a physics show that ends by awarding the best contraptions with prizes in different categories. The Chain Experiment competition is in many aspects similar to a variety of national and international physics and science competitions in Europe, but at the same time unique. Team working and good communication skills are strong assets in most of competitions such as the International Young Physicists' Tournament (IYPT), The European Science Olympiad (EUSO), International Junior Science Olympiad (IJSO), etc [20–24]. There are of course similarities between these competitions, such as following certain rules and determining the winning team or individual. Without going into details of the competitions mentioned above there are a few important differences between those and the Chain Experiment. Most importantly the competitive character of the Chain Experiment comes second. The satisfaction of being part of a well operating chain and thereby exhibiting an ingenious contraption that is a product of a whole team one is a member of is the most important motivation of the participants. The awarded prizes are just additional stimuli. During the competition an overwhelming sense of collaboration and support among the participating teams is felt [25]. Their common goal is to make the chain operate flawlessly several times during the course of the day. Another important difference is that the competition is open to all age groups, so kindergarten children and their mentors are joining efforts with high school students or seniors. Last but not least, science or physics competitions usually have a relatively rigid syllabus or problems that are defined in advance. The Chain Experiment is much more open in this respect—besides the prescribed linking steel ball and the safety and logistical regulations the constructors are left entirely to their imagination and abilities.

The best contraptions are selected in two different ways. There is a jury of three judges that inspects all contraptions and grades them according to well defined predetermined criteria, such as reliability, design, demonstrated physical phenomena, innovation, technical perfection, ingenuity, etc. As the jury is assessing contraptions by diverse criteria, we strive to have a diverse jury—besides a physicist and a technically educated judge, one member of the jury is usually also an expert in the field of art or design. The assessment of the contraptions takes place during the runs of the chain as well as during the breaks, when the judges have a closer look at the contraptions and ask the constructors about the ideas behind the contraptions or how precisely the contraptions work. Each year the jury as a rule awards three prizes. The second type of award is the so called audience award and the selection is done by the

Figure 4. The label of the CD ROM containing the video of the first Chain Experiment: the contraption ‘*The Castle*’ by a kindergarten group won the audience award, the girl is one of the performers in the accompanying program, a crowd of spectators is fascinated by the chain of contraptions. © DMFA založništvo, Ljubljana, Slovenia, used with permission from Professor Dr Peter Legiš and Professor Dr Dragan Mihailović.

audience. The visitors vote for the best contraption in their opinion by circling the contraption number on a ballot paper they receive on arrival at the event. Constructors are not allowed to vote for their contraption.

The whole event usually lasts half a day for the audience and a couple of hours more for the competitors, as they have to prepare the contraptions before the show. Throughout the event the Chain Experiment is set in motion at least three times. During the breaks between the runs there are physics shows prepared by the students or teachers, runs of the demo chain experiment, and also cultural or other exhibitions or shows usually related to the location of the event. Finally, the competition ends with the award ceremony. The beauty of the competition is in the fact that each year a completely different chain with entirely new contraptions is set up. One of the regulations prohibits the competitors from using the contraptions from previous years.

To conclude the description of the national competition, some statistics seems appropriate. The first run of the Chain Experiment in May 2005 was actually also the largest one so far. It was inspired by the World Year of Physics and therefore we were able to mobilise many schools, kindergartens, and individuals. The Chain Experiment was a total success with a chain over 80 m long made from 53 contraptions, more than a thousand spectators, and a video to record the event for posterity (figure 4). There were three runs of the Chain, each lasting around 20 min, TV and radio stations making interviews and reports, a diverse accompanying program, and innovative awards.

Figure 5. Snapshots of the Chain Experiment in the Technical Museum of Slovenia in 2006 (left) and in the Slovenian Railway Museum in 2010 (right).

Figure 6. Snapshots of the Chain Experiment at the University of Ljubljana, Faculty of Education in 2015 (left) and in Gornjesavski muzej Jesenice in 2016 (right).

In each annual competition around 20 to 30 contraptions constitute the chain. The national competition is organised in locations across Slovenia, from the Technical Museum of Slovenia in Bistra near Vrhnika, where it was set in a beautiful garden of a former castle (figure 5, left), to the large exhibition hall of the Slovenian Railway Museum in Ljubljana (figure 5, right), where we made a video of the 2010 competition [25], the reception hall of the Faculty of Education in Ljubljana in 2015 (figure 6, left), and at Gornjesavski muzej Jesenice, where it was turned into a joyful science fair with hundreds of visitors in 2016 (figure 6, right).

We would like to make the competition international, which we to some extent managed already. In 2013, a Polish group of organizers launched the preparation of an analogous competition in Poland. We helped them to promote the idea with some of our demo chain contraptions [12]. They adopted our basic rules and in 2014 the first national competition in Poland was carried out on the same day and at the same time as in Slovenia. We established a video-conference between both events and the audience could watch a live broadcast of one

run of the chain in the other country. In Poland the chain experiment competition has already become an annual event with many participating contraptions.

The educational impact of the project

To evaluate the project and to estimate its significance in view of physics education several aspects need to be considered. In order to do this systematically the concept of *four pillars* is introduced first and next each of the four is discussed in detail. From the standpoint of human resources the project Chain Experiment is based on four pillars:

- the organizers and financial supporters,
- the university physics students,
- the mentors,
- the constructors.

The role of each pillar's members in the activities of the project and the role of the same members in the educational system determine the impact of the project on the members.

The organizers and financial supporters

The roles of the three institutions cooperating in the organisation of the Chain Experiment activities are distributed according to their role in society. The impact of the project on the three institutions is not as important as on the other three pillars, but their supporting role is of course crucial for the project. All of the organizing institutions to some extent provide financial support. The Technical Museum of Slovenia in particular helps with logistics by organizing transportation and helping to find suitable locations for national competitions, for example in different museums across the country, and also by providing expert personnel at the national competition. The Society of Mathematicians, Physicists and Astronomers of Slovenia is the cover Slovenian organisation that promotes physics, astronomy, and mathematics. It has been doing so for more than half a century. With its high reputation for impeccably organised national competitions in the three fields at all age levels it provides a safe haven for the Chain Experiment project and enables participation in national and international tenders for science promotion. It also financially supports a significant proportion of the project. The University of Ljubljana, Faculty of Education, is currently the home of the demo chain experiment and provides the main pool of university staff that coordinates all three activities of the project and also the main pool of physics students that participate in all aspects of the project, acting as demonstrators and organizers, as well as sometimes constructors of contraptions. The financial support from the Faculty is of the same order as that of the Society.

On one hand, participation in the project represents promotion for the institutions. On the other hand, the activities of the project provide alternative ways to promote science in general and physics in particular. From the physics education point of view, the largest impact of the project is observed at the Faculty of Education, providing additional experience and learning opportunities for staff members and participating students. This brings us to the second pillar, discussed in the next subsection.

The university physics students

So far it was not stressed enough that the contribution of physics students to the project is irreplaceable. The students represent the working force of the project, taking an active part in

all three activities of the project as demonstrators or animators, maintaining and repairing the demo chain contraptions, etc. At the same time there is a considerable gain for the students in the project as well.

When the students accompany the demo chain experiment across the country they practice addressing different audiences—explaining physical concepts in the contraptions to young children, primary school teenagers, high school students, adults, or elderly people, all with different educational backgrounds. Not only do they have to understand the physics, they also learn how to transfer their knowledge to different target audiences. In the team building events they act as animators motivating the teams to overcome possible blockages during the analysis of the contraptions and gradually giving them hints on the operation of their contraption. This, for example, raises the student's sensitivity to detect the needs and provide adequate support for the learners to grasp difficult concepts. At the national competition, on the other hand, physics students must provide technical help to the participants. All this is a valuable addition to their relatively limited practical work during their studies. Namely, the two week praxis during their 3rd and 4th years of study consists of at most 20 classes of physics given usually to primary school pupils (age 13–15). In the course of working in the Chain Experiment project the students also develop a positive attitude towards practical work, team work, and embrace the positive influence of the Chain Experiment on school-age children, which is addressed in one of the following sections. At the Faculty of Education a sort of student working cycle has been established. In the first or second year of study, physics students interested in the project are recruited and introduced to various aspects of the project. Some students become strongly attached to the project and many of these students become mentors of the constructors when they teach at schools. Therefore, all involvement in the project helps future physics teachers in their personal and professional growth.

This positive influence on physics students at the Faculty of Education is at the same time a great motivational element for the faculty pedagogical staff to keep the project running in spite of many other obligations and the relatively large time investment for the project to continue and evolve. Around ten students take part in the Chain Experiment project each year, and besides their participation in the national competition, they also carry out on average around 10–15 demo chain shows and around 10 team building events each year.

The mentors

It has already been pointed out that the Chain Experiment competition is unique in the sense that the cooperation among teams to make the chain work is ahead of the competitiveness between them to win one of the awards. The reason for such a unique attitude is to large extent due to the fact that the competition is at the same time an exhibition of the contraptions. As such it is an opportunity to place the contraption in a large chain and thereby be a part of something bigger. The accompanying show is itself a reward for the work of the team during the entire school year. And this is where the impact of the project on the mentors of the teams comes in.

In contrast to other knowledge oriented competitions where the end scores matter the most, the mentors of the contraption building teams report that the process is much more important than the final outcome. Preparation of the ideas of the pupils or students, their presentation, discussion of the underlying physics, solving the technical problems of construction, testing and improving the contraptions all serve an enlightened teacher to provoke interest for physics and technology in his apprentices and to teach them physical concepts in a playful goal oriented way. The teachers/mentors can enhance manual skills and communicating abilities of the students through the design and realization of the ideas, as well as

encourage the students to provide new and original ideas thereby provoking their divergent thinking. Training the students to work in a team is also a very important educational objective of the project that a teacher cannot easily carry out during regular classes.

One of the teachers, a mentor of several teams each year, states that one of the main factors that affect the final product (a working contraption and a successful participation in the competition) is the enthusiasm of the learners and the mentor. When studying he started as an enthusiastic constructor of one of the first demo chain contraptions, and later became a passionate promoter of the Chain Experiment competition as a young teacher. After developing and improving his recruitment strategy for a couple of years, he managed to motivate almost half of his physics class pupils aged 13–15 to prepare contraptions for the national competition. He reports that a very efficient motivation for pupils turns out to be the emphasis on the similarities between the procedures in the everyday lives of the students and in the construction of the contraptions. According to him there are three typical phases in both cases: planning, producing, and testing. In his experience taking part in the project therefore equips pupils with general skills important for their adult lives [26].

There is a particular reason for having most constructors coming from the last years of primary school (pupils age 12–15). In Slovenia the university educational programs for formation of primary school teachers for a particular subject is as a rule two-subject oriented. That means that many of the physics teachers are also licensed to teach mathematics or technology. Furthermore, the majority of primary schools have technical workshops and special physics classrooms or laboratories with a sufficient collection of tools and equipment to enable processing different materials such as wood or metal, or performing experiments. This empowers in particular teachers of physics and technology to be able to help students by letting them work in the school workshop or laboratory under their supervision or by making same particular parts for the contraption themselves. High schools are in general less equipped, and at the same time teachers in high schools are usually licensed to teach only one subject. Those physics and technology teachers that participate in the Chain Experiment competition on average agree that participation in the project is rewarding because the pupils that participate in the project are much more motivated for both subjects and to some extent pass this feeling to their peers in the class.

The constructors

From all that has been written in the last section it is already clear that participation in the contraption design and construction is beneficial for the participating pupils and students in many ways. In addition to the already mentioned facilitated learning of physics and newly acquired manual skills there are other positive consequences. Participants see many positive aspects of their work and learning during the preparation process and building of a contraption, i.e. they develop their communication abilities, technical skills, physics concepts, research skills and gain positive experience through teamwork. Participants appreciate learning by working and learning through interaction with others; they find it much more pleasant than classical learning of physics. In addition, they find constructing the contraptions to be one of the most productive ways of spending the time with their peers. The project also gives participants a unique possibility to test the process of making a final product from an idea. Besides producing different ideas and discussing those at the beginning, they learn how all the intermediate phases are important as well—designing, making parts, setting up or building, and finally testing and correcting or improving the original design. Along the way they learn to communicate ideas and to constructively criticise each other's suggestions, including the mentor as a supervisor. Another important lesson is to learn to be patient and

persistent in searching for solutions to overcome difficult situations when it may seem that there is no way out, etc.

Although the majority of the national competition participants are primary and partly secondary school students with teachers as mentors, other collaborations occurred as well. Over the years it has become evident that two types of cooperation are particularly fruitful. Children from kindergartens backed up with the help of their parents and encouraged by their teachers form one type of these teams. The other type of collaboration is formed by youngsters aged between 10 and 18 as constructors and enthusiastic retirees as mentors. Both types of collaboration produce interesting and well thought out contraptions that are also skilfully made in every single detail, which significantly increases their aesthetic value. This intergenerational integration is beneficial for all parties involved. For example, retirees transmit practical skills and share their experiences, while youngsters provide many wild ideas that can or cannot be incorporated in the contraption. This dynamics in the construction process is provoking motivation on both sides, regardless of when youngsters and their grandparents or kindergarten children and their parents are concerned. The youngsters gain knowledge and skills they would not be able to obtain within the usual teaching process and the parents or grandparents spend some quality time with their offspring.

The ingenuity

Many positive aspects of the project have been pointed out in the paper, and before concluding a few words about the physics and other interesting contents in the contraptions is appropriate. Since the constructors are given complete freedom regarding the content of a contraption, a large variation and many levels of complexity are found in the contraptions. Some of them are very simple, based mainly on changing the potential energy of the steel ball into the kinetic energy and triggering other balls or similar objects by the ball rolling down. On the other hand, a contraption may be extremely complex and based on various different physical phenomena, so that it would require an entire separate paper to explain and illustrate its operation. Therefore we limit this short section to name just a few interesting phenomena and some general properties of the more elaborate contraptions.

The most interesting particular phenomena observed in the contraptions presented in the national competitions so far include (among others) the following. A siphon (Pythagorean cup) was used to transfer a large amount of liquid by adding a small object or a small amount of liquid into a container [13]. Fast rotation of a heavy disk was preventing it from falling and causing it to precess [15]. Adding soapy water lowered the surface tension of the water thereby releasing one arm of a lever. A drop of dishwashing detergent was dropped into the water to push a small specially shaped boat initially floating at rest by locally changing the surface tension [16]. One contraption incorporated optical illusions such as a mechanically animated motion picture. A device similar to the Archimedes screw was incorporated in a contraption to lift the steel ball. A copper wire and an AAA battery with two neodymium magnets were used to make an ‘electromagnetic train’ that triggered another part of the contraption.

There are other particular physically interesting phenomena found in the contraptions, but there is a whole other aspect that also shows the creativity of the constructors. For some contraptions there were short stories behind the operation of the contraption. For example, one contraption resembled the process of harvesting wood from the forest. Yet another included an emergency call, followed by the arrival of the fireman’s car and moving the ladder to save a person from a burning house. In another one a skiing resort was mimicked by a white slope and a cable car that lifted a steel ball representing a skier and letting it roll down

the skiing trail. Some contraptions included musical instruments or parts of them and played a known tune while operating.

A particular challenge that only a few constructors dared to address was to move the same steel ball that triggers the contraption throughout the entire contraption and into the next one. The ones incorporating this successfully were skilled retirees that included an elevator to lift the ball to the required height.

Conclusions

In the paper the Chain Experiment project and the ten years of its history and evolution are presented. In a decade it affected generations of students of all ages, their mentors, and individual adults. We show the variety of activities that are addressing different target groups and how the project is beneficial for each of them. In particular we show how physics students and mentors grow professionally and personally by participating in the project. On the other hand the constructors profit immensely, acquiring new team working, communication and manual skills. We demonstrated how the project facilitates learning of physics and raises the motivation of pupils towards science in general.

We have presented the Chain Experiment as a particular kind of competition in which participating and preparing contraptions for the competition is more important than winning, and in which the competing teams closely collaborate during the competition rather than individually striving for awards on account of other competitor's failure. Finally, we have listed some of the intriguing physical phenomena that were incorporated in some of the most interesting contraptions so far.

Although each year having around 20 contraptions in the final Chain Experiment competition may seem a small number, for a country with 2 million inhabitants we consider it a fair number. Even more importantly, the number is stable and many recognise the name Chain Experiment as a synonym for science and physics promotion in Slovenia.

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References

- [1] University of Ljubljana, Faculty of Education, official website (www.pef.uni-lj.si) (last accessed 3 February 2017)
- [2] The Society of Mathematicians, Physicists and Astronomers of Slovenia, official website (www.dmfa.si) (last accessed 3 February 2017)
- [3] Technical Museum of Slovenia, official website (www.tms.si) (last accessed 3 February 2017)
- [4] Kalan M Youtube user 'chainexperiment', Verižni eksperiment (www.youtube.com/watch?v=hiJkdpymDqI) (last accessed 3 February 2017)
- [5] Chain Experiment, national competition website (www.verizni.si) (last accessed 3 February 2017)
- [6] Team Building Lab, official website (www.teambuildinglab.si) (last accessed 3 February 2017)
- [7] Susman K, Bajc J, Renema J, Herbschleb K, Drevenšek Olenik I and Voetmann C 2008 Physics shows in Europe *Frontiers of Physics Education GIREP—EPEC Conf. 2007* (Rijeka: Zlatni rez Rijeka)

- [8] Susman K, Bajc J, Renema J, Drevenšek Olenik I and Voetmann C 2008 Spread of show physics in Europe *Europhys. News* **39** 8–9 (http://europhysicsnews.org/index.php?option=com_toc&url=/articles/epn/abs/2008/01/contents/contents.html)
- [9] Bajc J and Verdel N 2014 Verižni eksperiment—aktivnost za nadarjene *Spodbudno učno okolje: ideje za delo z nadarjenimi v osnovni šoli* ed M Juriševič (Ljubljana: Ljubljana Univerza v Ljubljani, Pedagoška fakulteta) pp 229–34 (www.pef.uni-lj.si/fileadmin/Datoteke/Zalozba/prodaja_predstavitev/Jurisevic_SUO.pdf)
- [10] Dreiner H K 2008 A physics show performed by students for kids: from mechanics to elementary particle physics *Phys. Teach.* **46** 358–62
- [11] Roche J, Stanley J and Davis N 2016 Engagement with physics across diverse festival audiences *Phys. Educ.* **51** 045007
- [12] Dziob D, Górska U and Kołodziej T 2017 Chain experiment competition inspires learning of physics *Eur. J. Phys.* **38** 034002
- [13] Štrus D 2005 Verižni eksperiment *Presek* **32** 21–3
- [14] Lasič S and Potočnik A 2005 Tretji in četrti člen verige eksperimentov *Presek* **32** 11–4
- [15] Mah M and Hladnik P 2005 Peti in šesti člen verige eksperimentov *Presek* **33** 10–3
- [16] Rovsek B and Kusar T 2005 Sedmi in osmi člen verige eksperimentov *Presek* **33** 20–4
- [17] Vaupotic N 2006 Deveti in deseti člen verige eksperimentov *Presek* **33** 14–5 and 19–20
- [18] Salas E, Diazgranados D, Klein C, Burke C S, Stagl K C, Goodwin G F and Halpin S M 2008 Does team training improve team performance? A meta-analysis *Human Factors* **50** 903–33
- [19] Massachusetts Institute of Technology Museum, Friday After Thanksgiving Chain Reaction website (<https://mitmuseum.mit.edu/fat>) (last accessed 3 February 2017)
- [20] Jordens H and Mathelitsch L 2009 Physics competitions *Eur. J. Phys.* **30** S101–4
- [21] O’Kennedy R, Burke M, van Kampen P, James P, Cotter P, Browne W R, O’Fágáin C and McGlynn E 2005 The first EU science olympiad (EUSO): a model for science education *J. Biol. Educ.* **39** 58–62
- [22] Paul van K *et al* 2004 A new science competition for secondary school students: the first European Union science olympiad *Eur. J. Phys.* **25** 23–9
- [23] Planinšič G 2009 IYPT problems as an efficient source of ideas for first-year project laboratory tasks *Eur. J. Phys.* **30** S133–40
- [24] Haskell H, Britton C and Edge R 2000 A different kind of physics competition—the IYPT *Phys. Teach.* **38** 22
- [25] Mlinar C 2010 Technical Museum of Slovenia (producer) Verižni eksperiment Youtube user ‘chainexperiment’ (<https://youtube.com/watch?v=k6nFDeosL-M>) (last accessed 3 February 2017)
- [26] Udovč G 2012 Verižni eksperiment kot interesna dejavnost v OŠ *Fizika v šoli* **18** 108–13