

Development of students' interest in particle physics as effect of participating in a Masterclass

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received 26 October 2015

Summary. — The International Hands On Particle Physics Masterclasses are enjoying increasing popularity worldwide every year. In Germany a national program was brought to live in 2010, which offers these appreciated events to whole classes or courses of high school students all over the year. These events were evaluated concerning the issues of students' interest in particle physics and their perception of the events. How several interest variables interact with each other and the perception of the events is answered by structural equation modelling (sect. 5'2). The results give information about the events' effects on the students' interest development in particle physics, show which event features are important (*e.g.* the authenticity) and give information about practical approaches to improve the effects of the Masterclasses. Section 5'3 deals with a group of participants which have a high interest in particle physics 6–8 weeks after the participation. The number of these students is remarkable large, with 26% of all participants. The investigation of this group shows that the Masterclass participation has the same positive effect on both sexes and all levels of physics education.

1. – Introduction

An important concern of physics education is the support of interest in physics issues and phenomena (cf. Berger 2011, p. 99). This interest creates a basis for young people to deal with scientific questions and their social connections, beyond the school education, *i.e.* “to become lifelong learners and to maintain a sense of wonder about the world around them” (cf. BMBF 2007, p. 158). Another aim of physics education, in addition to the teaching of content, is to offer an insight into modern research processes and questions. These issues enable students to get an adequate picture of nature of science and scientific knowledge gain.

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All these issues are taken up by events about particle physics for high school students, so called “Particle Physics Masterclasses” offered by the German national program “Netzwerk Teilchenwelt” (English: network particle world). This is a network of 24 German particle physics research institutes and CERN⁽¹⁾. In this network high school students, physics teachers and particle physicists, who are involved in the program, are enthusiastic about particle physics. The network offers a wide range of activities for students and teachers whereof the Particle Physics Masterclasses build the basic level. This contribution deals with the evaluation of these events, concerning the supporting effects on students’ interests in physics and particle physics. Some important results of this evaluation study are presented.

2. – The Particle Physics Masterclasses

The Particle Physics Masterclasses are inspired by the International Hands On Particle Physics Masterclasses, which take place every year in March around the world. With the network’s offering of the Particle Physics Masterclasses, high school students can join comparable workshops all over Germany throughout the year and it is possible that whole classes or courses of high school students can participate in such a Masterclass. Every year the network conducts about 120 Masterclasses. They last between 4 to 6 hours and mostly take place in schools with whole classes or courses. The facilitators of these workshops are young particle physicists, typically PhD students who sometimes are assisted by school students or teachers.

Such a Masterclass typically starts with an introductory talk of the young facilitators about the particle physics research, how it is conducted, how scientists work together in an international collaboration, which questions are answered or should be answered by the actual research, why particle accelerators are that huge, how a particle detector like the ATLAS detector⁽²⁾ is working etc. Then the participants get an introduction and exercise how to identify particles by analysing their detector traces. Afterwards the high school students do own measurements with original data from CERN. Thereby they typically work together in pairs to classify about 50 to 100 decay events into different categories. The results of all groups are combined. In a joint discussion, by using statistical methods, they achieve a fundamental result of the recent particle physics research.

The overarching aim of the Masterclasses is to give high school students an insight into the modern physics research, especially the particle physics research, in an authentic way. The authenticity includes on one hand making original data from CERN available for high school students and teachers. On the other hand the authenticity should be achieved by the creation of an authentic setting in the Masterclasses. This includes the direct contact with real scientists, the use of a software which is close to the one which is used by the scientists and applying similar methods to interpret and compare their results with the predictions within the standard model of particle physics. A central aim is to support the students’ interest development in particle physics. Individual students should be stimulated to do particle physics in their free time or *e.g.* to join voluntarily the higher levels of the network program. (cf. Gedigk *et al.* 2014, p. 397).

⁽¹⁾ Conseil Européen pour la Recherche Nucléaire (European Organization for Nuclear Research) near Geneva, Switzerland.

⁽²⁾ ATLAS in one of the four particle detectors which is used at the Large Hadron Collider at CERN

Students or teachers interested to know more about particle physics than they experienced by attending a Masterclass, can join the higher levels of the network program. For high school students the possible activities in the higher levels are proliferating their experiences with particle physics, participating in workshops or project weeks at CERN or conducting their own research projects.

3. – Research questions and theoretical frame

The objectives of the evaluation study are twofold: 1) the examination of the effects of the Masterclass participation on the students' interest development in particle physics, 2) to provide indications how the effect of the Masterclasses could be improved, especially concerning the implementation of the events.

The basis of this investigation is formed by the person-object-theory of interest by Krapp: "An interest represents a [...] specific relationship between a person and an object" (Krapp 2002, p. 387). Object in this respect "can refer to concrete things, a topic, an abstract idea, or any other content of the cognitively represented life-space" (Krapp 2002, p. 387). The interest relationship between the person and the object is characterized by cognitive, "value-related and feeling-related valences" (Krapp 2002, p. 388). This means that the person which is highly interested in an object (in best case) feels cognitively activated and "subjectively affected" by the object of interest of and experiences a "relevance for his or her sense of self" (Krapp 2002, p. 388). For that reason it is useful to distinguish between cognitive, emotional and value-related components of an interest relationship.

The more often and the more intensive a person interacts with the object of interest the more stable the interest relationship becomes. Furthermore, the development of this relationship also depends on the situation or the context in which the person is operating with the object (Krapp 1992, p. 308).

Another aspect for developing interest is the learning in an authentic setting (*e.g.* cf. Kuhn *et al.* 2010, pp. 6, 10; cf. Euler 2009, pp. 802, 805). Therefore to evaluate the perceived authenticity of the event was an important aspect of the investigation. On the other hand it is difficult to achieve long-term effects on the interest by a one day event (cf. Euler 2009). However, as particle physics does only play a small role in the German school curricula, the special interest in this topic is assumed to be influenceable by a Masterclass participation. The interest in physics as a subject and as profession is assumed to be relatively stable, because they were created over several years of physics education. The crucial factors for being engaged to do particle physics beyond the Masterclass are supposed to be the interest in particle physics itself, the (realized) intended actions of interest in particle physics and the interest in participating in the network.

From this the research question follows: How does the authentic setting of this one-time event affect students' interest development in (particle) physics? Concretely the following questions are examined in this article:

- Are students' interests in physics in general and particle physics in particular fostered by a Masterclass participation?
- Can long-term effects be seen?
- Are there differences in the interest development between several participant groups? (*e.g.*, gender, age, type of school, etc.)

- How do different interest and event variables affect each other? Especially which event properties are related to interest changes and which factors can be identified, that are crucial for a positive perception of the events?
- Is there a group of participants with a high interest in particle physics after the Masterclass? What is characteristic for this group (*e.g.*, age, type of school, gender, etc.)?

4. – The evaluation study

To measure the different aspects of interest of the participating high school students an interest questionnaire was developed, tested in a pilot study and then improved. It is based on existing interest questionnaires which were recently used to evaluate out-of-school learning laboratories (*e.g.*, Pawek 2009, Engeln 2004) and was adapted to the specific format and content of the Particle Physics Masterclasses. It contains items with closed answer format with a 5-point Likert scale.

For determination of the interest changes the evaluation study follows a pre/post/follow-up design. The students filled in the questionnaire at the beginning, at the end of the Masterclass and again after a 6 to 8 week period. The follow-up evaluation enables the investigation of the sustainability of the Masterclasses. Additionally a control group was evaluated with the same instruments and the same procedure, which means that students attending the same school levels were asked, who did not take part in a Masterclass.

Figure 1 shows a selection of the evaluated variables. As described in sect. 3 we distinguish relatively stable and changeable interest variables. It was considered important to ask in the follow-up evaluation for realized “actions of interest” as this was an indicator for the interest of taking part in the higher levels of the network program. For that reason these variables are called target variables. One of the control variables were the “perceived event features”. Examples for the items and the internal-consistency coefficients (Cronbach’s alpha) of the variables are presented in Gedigk *et al.* (2014, p. 404).

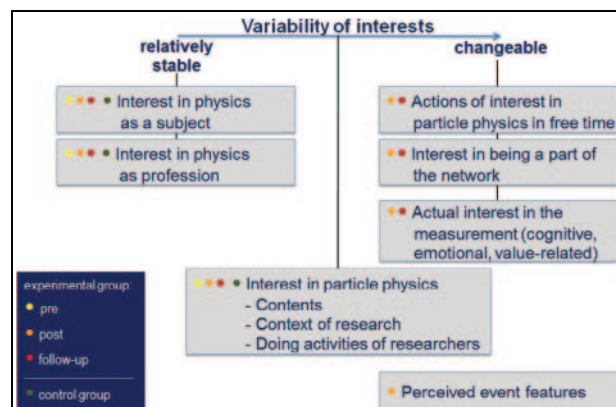


Fig. 1. – Selection of evaluated variables with the assumed stability.

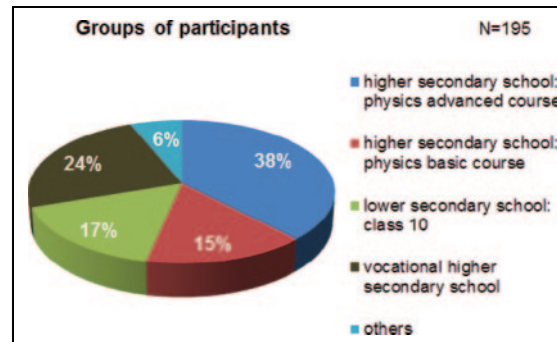


Fig. 2. – Groups of participants in the experimental group.

5. – Selected results of the evaluation study

The evaluation study was conducted from October 2011 until May 2012 in 25 Particle Physics Masterclasses with about 500 high school students (“experimental group”). In this article selected crucial results are presented below. More results, for example the comparison between experimental and control group, can be found in Gedigk *et al.* (2014).

5.1. Description of the sample. – The experimental group consists of four main groups with different educational background, shown in fig. 2. It describes the participants of the evaluated Particle Physics Masterclass ($N = 195$) without those students, who already attended a Masterclass before and without students with incomplete data. Furthermore only students attending with their whole class or course were included. Individual students (“selected students”) were excluded, because this group shows much higher pre-interests in comparison to the group of whole classes or courses.

A fifth of the experimental group is female. About 86% of these students state, they did not have the choice whether to participate or not. But 89% declare that they looked forward to the Masterclass.

5.2. The mechanism behind interest development. – To investigate how different evaluated variables are related, a structural equation model was developed. The model offers an overview how the one-time intervention of participating in a Masterclass affects students’ interest development in particle physics. It was developed on the basis of the interest construct theory (sect. 3) and chronological considerations. According to the aims of the Masterclasses (see sect. 4) the most important long-term *target variables* are the interest in particle physics and (realized) intended actions of interest in particle physics in the follow-up evaluation (marked blue in fig. 3). As one of the goals of the evaluation is to get hints for optimization of the Masterclasses (see sect. 4) in the centre of the model is the *focus variable* of the perceived event features (marked orange), because this among other things also depends on the implementation of the Masterclasses.

The structural equation model was implemented with the statistical software AMOS 22, using maximum likelihood estimation. Key elements of the model are the seven latent variables, which are presented with an elliptical shape in fig. 3. Each of them is related to two or three directly measured variables which are represented with rectangular shape. This is based on the assumption that recently measured variables and their correlations

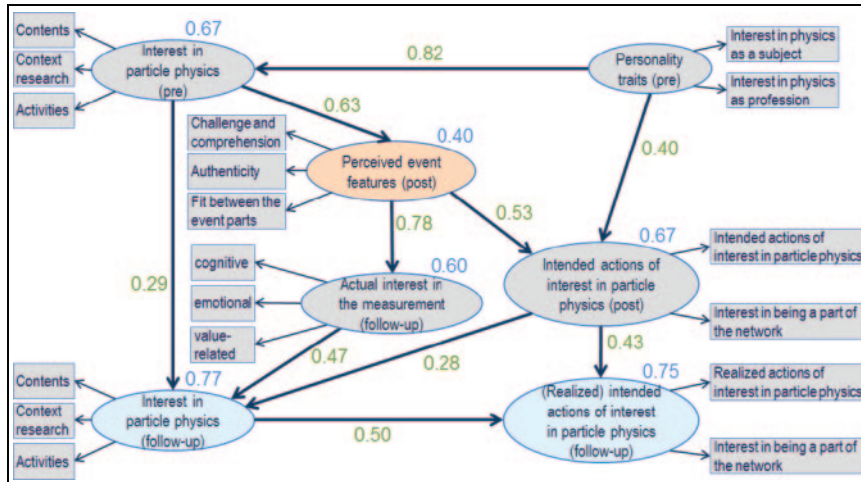


Fig. 3. – The mechanism of action between the interest and event variables. Arrows: (directed) regression paths. Variables with elliptical shape: latent (or unobserved) variables. Variables with rectangular shape: measured (or observed) variables, indicators of the according latent variables. Green numbers: estimated standardized regression weights; all of them are significantly different from zero at a 0.001 level. Blue numbers: estimated proportion of the variance of the variable that is accounted for by its predictors.

can be explained with a non-observable (= latent) background variable. Particularly important are the directed connections between the latent variables, which represent regression paths. These are based on theoretical and chronological considerations (cf. Kline 2012, p. 113).

The numbers given in the model are estimated values which have the minimal difference to the data w.r.t the maximum-likelihood estimation. Blue numbers stand for the estimated proportion of the variance of the according latent variable, “that is accounted for by its predictors” (Arbuckle 2012, p. 74). For example, 67% of the variance of the interest in particle physics at the beginning of the Masterclass is explained by the personality traits. The green numbers are estimated standardized regression weights of the according regression path. For example, if the personality traits of two persons are compared, the person with a higher personality trait of one standard deviation is expected to have a higher interest in particle physics at the beginning of the Masterclass by 0.82 standard deviations (*i.e.* 82% of the standard deviation). Furthermore the model gives information about the most important effects and several effect sizes. The model fits the data very well, as several fit indices confirm, as shown in table I. We choose as criteria the most commonly used fit indices (*e.g.* Pawek 2009, p. 150, Rudolf 2012, pp. 355–358). Concrete formulae for these indices can be found in West *et al.* (2012, pp. 212 ff).

We start the explanation of the model shown in fig. 3 from the focus variable (perceived event features). It is assumed to affect the target variables via the intended actions of interest in particle physics at the end of the Masterclass and via the actual interest in the measurement in the follow-up evaluation.

On the one hand, the focus variable of the perceived event features depends on the real event features, which may be influenced by the implementation of the events. On the

TABLE I. – *Fit indices for structural equation models. χ^2 : chi-square statistic; df: number of degrees of freedom; CFI: comparative fit index; RMSEA: Root Mean Square Error of Approximation; SRMR: Standardized Root Mean Square Residual. Criteria for the indices, cf. West et al. (2012, p. 212, 213, 219), “ ω ” cf. Rudolf et al. (2012, p. 365). Right column shows the values for the model depicted in fig. 3.*

Fit index	Criterion for good fit	Criterion for acceptable fit	Values for our model
χ^2/df	$\leq 2.5^\circ$	< 5	1.825
CFI	≈ 1	> 0.95	0.955
RMSEA	< 0.05	< 0.08	0.065
SRMR	< 0.05	< 0.10	0.052

other hand, it also depends on the subjective individual perception. Pursuing this path further backwards the relatively stable personality traits, which represent the interest in physics as subject and profession, in general, act via the special interest in particle physics on the perception of the event.

As can be seen in fig. 3 the paths via the focus variable of the perceived event features have an influence on the long-term interest development in particle physics. The comparison of the standardized regression weights shows that the influences on the long-term target variables of the perceived event features are in a comparable size (dimension) to the direct effects of the personality traits and the interest in particle physics at the beginning of the Masterclass. But the model shows also that these latter variables affect the perception of the event, so that 40% of the variance of the perceived event features is explained by them. For this reason table II shows the standardized total effects of these and the perceived event features on the long-term target variables, which means that direct and indirect effects are added to a total effect. A standardized total effect corresponds to a standardized regression weight. The determined values of the standardized total effects show again that the perceived event features affect the long-term target variables in a comparable effect size to the personality traits and the interest in particle physics at the beginning of the Masterclass.

As these results show the perceived event features have a relatively strong influence on the students' long-term interest development in particle physics. This is a surprising result, because the Masterclass is an one-time event, which only lasts between 4 to 6 hours. Results from comparable recent studies show that such one-time events do not have a big influence on long-term special interests (*e.g.*, Pawek 2009, p. 151).

The following question immediately raises: which factors affect the perception of the event features, besides the personality traits and the interest in particle physics in the

TABLE II. – *Standardized total effects, columns affect rows.*

	Personality traits (pre)	Interest in particle physics (pre)	Perceived event features (post)
Interest in particle physics (follow-up)	0.61	0.61	0.51
(Realized) intended actions of interest in particle physics (follow-up)	0.60	0.45	0.49

pre evaluation? Especially, which objective event properties have an influence? Some answers are given in Gedigk *et al.* (2014, p. 402): The perception of the event features depends, *e.g.*, on the prior knowledge in particle physics, the gender and the type of measurement.

In summary, the developed model fits the data very well and it shows that the event variables have a considerable influence on the long-term interest in particle physics of the young participants. It gives information about practical approaches to improve the Masterclasses' effects and can be used for further investigations of these events.

5.3. Group with high interest in doing particle physics after participating in a Masterclass. – The Masterclass participation can be called particularly successful for those participants, who are interested in doing particle physics beyond the Masterclass (cf. aims of the Masterclasses, sect. 2). For this reason it is investigated, if there is such a group and what characterises this group (cf. research questions, sect. 3).

The evidence for a long-term interest in particle physics are the (realized) intended actions of interest in particle physics in the follow-up evaluation. It plays no role if the students intend to be a part of the network or if they do actions of interest in particle physics in their free time. So on the basis of the questionnaire students were chosen who had a high interest in being a part of the network (upper 20% of the participants) or who realized actions of interest in particle physics (also upper 20%). This resulted in a group of 51 participants of 195 (cf. sect. 5.1), corresponding to 26%. This group in the following is called “*success group*”.

To characterize this success group χ^2 -independence tests were used (cf. Bortz, Schuster 2010, pp. 137 ff.) for the investigation of the relation between this success group and gender and between the success group and level of education (grade or school type) (cf. sect. 5.1). These tests show the independence of the success group on gender ($\chi^2 = 0.99$; $p = 0.32$) as well as on level of education ($\chi^2 = 3.51$; $p = 0.32$). These are remarkable results, implying that practically all students have a similar probability to develop a long-term interest in particle physics.

For a further characterization of this success group it was investigated if the success group rate the perceived event features better than the other participants. Table III shows the results of the corresponding *t*-tests with the effect size Cohen's *d*. The success group indeed assesses the features better than the others with medium effect sizes (cf. Bortz, Döring 2006, p. 606), whereby the biggest difference occurs regarding to the authenticity. These results confirm the structural equation model shown in fig. 3.

Another remarkable characteristic of the success group is that there is no significant difference between the intended actions of interest in the post evaluation ($M = 2.68$, $SD = 0.87$) and the realized actions of interest in the follow-up evaluation ($M = 2.72$, $SD = 0.65$). This was tested with a *t*-test for paired samples ($t = 0.44$; $p = 0.67$). This means that this group realizes its intentions according to the actions of interest in the free time within those 6 to 8 weeks, which exceeds the expectations.

To sum up the success group shows that an interest in particle physics can be supported or stabilized for a considerable part of the participants. On the whole it seems that the potential for joining the higher levels of the network is much bigger than the network capacity (cf. Gedigk *et al.*, p. 397). It is a very positive result that the format of the Masterclasses seems to be able to sustain interest independently from gender and class or school form.

TABLE III. – Differences in the perceived event features between the success group and the others. Right column: Cohen's d as effect size for a significant difference between the means of the groups, t -test for independent samples was used with: ** $p < 0.01$ or *** $p < 0.001$.

Perceived event features (post)	Success Group ($N = 51$)		Others ($N = 141$)		Cohen's d
	Mean	Standard Deviation	Mean	Standard Deviation	
Challenge and comprehension	2.71	0.84	2.27	0.83	0.54**
Authenticity	3.04	0.69	2.63	0.65	0.61***
Fit between the event parts	2.67	0.81	2.30	0.83	0.45**

6. – Conclusions

A model was developed showing which variables are important for the interest development of the participants in a particle physics Masterclass. It fits the data very well (table I) and shows how interest and event variables influence each other (fig. 3). On the one hand, this offers the opportunity to find practical approaches for improving the effect of the events. On the other hand, it makes it easier to investigate the effects of Masterclasses again, *e.g.* when the implementation will be changed systematically. Furthermore the model (and the questionnaire) could be adapted for similar event formats, to investigate the interest development of the participants. It is remarkable that the event variables have a considerable influence on the students' interest development in particle physics (c.f. table II).

Section 5.3 describes a group of Masterclass' participants which have a high interest in being a part of the network or in actions of interest in particle physics, 6 to 8 weeks after the Masterclass participation. It is remarkable that this group is independent of gender and class or school form. Furthermore this "success group" is much bigger (26%) than the network capacity for joining the higher levels. So the Masterclasses have a big potential to inspire high school students for doing particle physics.

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We thank Michael Kobel for the possibility to evaluate the particle physics Masterclasses of the "Netzwerk Teilchenwelt" and for his support.

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