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Development of Inquiry Based Learning via IYPT

YPT TOOLKIT

A guide for implementing YPT-inspired activities in class and prepare teams for YPT competitions

International Young Physicists' Tournament

Title: YPT toolkit

Subtitle: A guide for implementing YPT-inspired activities in class and prepare teams for YPT competitions

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Table of contents

1. About the toolkit

The toolkit was born with a dual purpose. The format of the toolkit adapts to this duality:

In-class

1) On one hand we would like to deliver a toolkit for teachers on how to use the IYPT problems for Inquiry based learning in high school. The toolkit provides teachers with instructions and suggestions on how to organize the class and the time in order to develop scientific abilities. These parts are in green and are intended to assist teachers on how to implement IYPT tasks in a normal classroom environment. This can be an introduction to IYPT, but it can even be used to make lessons more colourful. We hope that our suggestions help to lead projects which can increase the number of students who are interested in physics.

IYPT

2) On the other hand, this toolkit is aimed to allow a broader spread of the IYPT platform by helping teachers and other educators to involve more students into it. It is a known fact that IYPT, while fully accepted as an extraordinary educational tool, has a high entrance barrier for both teachers and students. With the toolkit, we believe we can help both groups overcome this obstacle. The elements specifically important for actual YPT competitions are in blue and their basic purpose is to help prepare teachers for the International Young Physicists' Tournament (IYPT). We aimed to make some chapters directly applicable to students too.

General

3) There are many common points to both implementations. These are indicated in yellow. They contain information which is relevant for both in class YPT-like activities and YPT competition preparation.

2. Introduction

General

2.1. What is IYPT

IYPT is a team competition for high school students, which mimics, as much as possible, the process of actual research in physics. Each year at the end of summer, IYPT publishes 17 open-ended problems. The most distinctive feature of the competition is that the problems often do not yet have a known solution or the complete solution is too complex for high school students. This emphasizes that the goal is not to find the right answer, but to determine how good is the given answer. Students in teams of five investigate the problems until next summer, when the IYPT tournament takes place.[9]

At the tournament, in one "**physics fight**" 3 teams take the role of **Reporter, Opponent** and **Reviewer**.

the Opponent first challenges the Reporter to present one of the studied problems chosen by the Opponent. The **Reporter** has 12 minutes to **present** their solution to the problem.

The **Opponent** has 2 minutes for asking clarifying questions and then presents a **critical analysis** of the report (up to 4 minutes). The most interesting part is the following 10-minutes **discussion** between the Opponent and Reporter. The task of the Opponent is distinctive, because it is not to challenge the reporter's research, but to test its soundness, noting the strengths and shortcomings of both the solution and the way it was presented. The Opponent is expected to evaluate the task fulfilment, to test the Reporter's explanation of the phenomenon, pointing to possible flaws in the methodology, inaccuracies, misunderstandings and to question the validity of the conclusions drawn. Importantly, if the report is done well and no fatal flaws can be found, this should be acknowledged and the opponent still receives a good grade for a thorough examination. (During the discussion, the Opponent should not present its own solution but should react to the Reporter's solution only.)

The **Reviewer** has 2 minutes to ask questions to the Reporter and the Opponent. Then they **evaluate** the entire fight within 4 minutes. Among others, they are expected to assess the Reporter's presentation and conclusions, the Opponent' challenges and the Reporter's answers,

[9] The Austrian Young Physicists' Tournament (AYPT) variant differs only in the fact that teams consist of only three students instead of five, and the team does not need to have solutions for all 17 problems, but only three out of 17.

the depth and usefulness of the discussion, and to point to essential points missed (if any). The Reviewer should clearly state their own opinion on all the topics discussed during the debate.

Finally, the Jury asks short clarifying questions to all three contestants and grades the teams.

It's worth noting that each team could gain as many points from its opposition plus reviewing as from reporting. This stresses the focus on discussion and science communication as well as the ability to quickly comprehend and check another's work.

The Austrian Young Physicists' Tournament (AYPT) variant differs only in the fact that teams consist of only three students instead of five, and the team does not need to have solutions for all 17 problems, but only three out of 17.

The IYPT is an experiment-based competition. As such, great emphasis is given to the "scientific method" (see Section 3.2.). Many aspects of this method will be unfamiliar to the participating high-school students, who are mostly taught in a traditional way. However, many of these aspects can be introduced in regular lectures. A well researched approach to apply is the ISLE (Investigative Science Learning Environment) teaching method, which emphasizes the "scientific approach" besides scientific findings. There is a textbook [1] and a book of activities [2] available for further reference. If students experience at least parts of the "scientific approach" during regular lessons, then the elements of the approach will be familiar to them and the YPT format will offer an opportunity to experience the entire approach from start to finish. Several publications indicate broad benefits for students by engaging in open ended scientific educational activities (see Section 2.2.).

Before continuing to the next section, which describes the process of working on a YPT problem, we recommend that readers unfamiliar with IYPT read Appendix 5, which describes an entire in-class example, to get an idea of how it all works.

[1] Etkina E, Planinsic G and Van Heuvelen A 2019 College Physics: Explore and Apply 2nd edn. (San Francisco, CA: Pearson)
[2] Etkina E, Brookes D, Planinsic G and Van Heuvelen A 2019 Active Learning Guide for College Physics: Explore and Apply 2nd edn. (New York: Pearson)

2.2. IYPT and inquiry-based learning

Inquiry based learning is the best way to describe teaching/learning methods based on inquiry in the broadest sense possible. But, it is also used to describe a specific subset of such methods. To avoid confusion, when we mention IBL in this toolbox, we always intend the broad sense, since IYPT has its own approach to IBL and its own teaching/learning method.

Despite the recent wave of interest in IBL there is a lack of major international competitions evaluating pupils' skills of solving inquiry problems. Actually, the only contest to tackle this challenge, we are aware of, is IYPT (together with competitions which are derived from it and mimic most of its features, like IYNT).

It is remarkable that IYPT was born in 1988, long before IBL became a buzzword. It was conceived in the specific intellectual atmosphere of Moscow extracurricular schools intended to look for and nurture talents in maths and science. As top level scientists were also engaged there, it was quite natural to bring in methods, research topics and ethos from the research institutions.

Quickly enough IYPT outgrew its origins to become a truly international endeavour with wide representation and established its unique style but the initial drive to bring the "real-life" research experience to secondary school pupils remains intact. In 2013 it was awarded **the *International Union of Pure and Applied Physics' Medal*** for "outstanding contributions to international physics education".

2.3. IYPT = inquiry problems + discussion format + …

If one is to summarise what is so special with IYPT, it is the combination of inquiry problems and the discussion format of the competition (which mimics the old-style defence of an academic thesis with Reporter, Opponent and Reviewer roles).

The list of specific features is to be completed with:

- IYPT is a contest of **teams** and it requires a lot of teamwork.
- The aim of IYPT solutions is not to reach/calculate "the correct answer" as there is no such thing as "correct answer" here. IYPT is rather **conclusions-oriented**. Participants have to design and perform experiments, and to draw conclusions argued from the experiments' outcome.
- Participants work for months on the previously announced problems. All experiments, pondering and conclusions are already done before the competition.

The amount of experimental work involved and the expectations of defending the results in a discussion makes the competition quite challenging even for students who otherwise do well at solving theoretical problems.

IYPT problems are deliberately stated in a very broad way ("Investigate the phenomenon", "What is the dependence on the relevant parameters" etc.). This opens the door for different interpretations and teams may take quite different routes to tackle the same problem. As long as they stay within the statement, all routes are legitimate and teams will be judged according to the depths reached by their investigations.

3. Working on YPT problems in class and beyond

General

3.1. Preparation and problem selection

Any YPT related activities necessarily include a lot of experimental work. This means that

- some equipment must be available and
- time must be allowed for students to perform experiments.

The problem selection process is very different depending on whether we are preparing an in-class activity or a team for AYPT or for IYPT (and similar competitions).

- **The in-class** problems should be solvable by most students. They should also offer an additional challenge for the better students (see Appendix 5). They can also be outside the published IYPT problems for the year.
- **The AYPT** requires only three problems to be solved. This allows a similar selection as for in-class activities, however, only IYPT problems for the year can be selected.
- **The IYPT** requires at least 14 problems to be solved and at least a superficial understanding of the remaining three. Therefore, the selection options are limited. Nevertheless, using tactics during fights, a team can be successful with fewer problems solved.

In-class

Different schools have different experimental equipment. For an in-class activity, problems must be selected, which can be investigated with the available equipment. Note that to use the YPT method, it is not necessary that the problem is from the IYPT list of problems. The teacher can come up with their own problem (such as the oscillator example in Appendix 5), appropriate to the level of the students.

Different countries have differently organized physics lessons, but if 80 – 100 minute lessons are available (usually a double period) then YPT activities are best planned for such lessons. However, parts can be done in 40 – 50 minute lessons, as described in the Appendix 5 introductory example.

When preparing for **open-ended school projects**, the teacher examines the potential problems that can be offered to his students. The most important elements to take into consideration are:

Is the task experimentally feasible? This includes:

- Does it require specialized tools? If you do not have them, it is not worth investing in theoretical research, since YPT activities are based upon experimental observations.
- Is it safe?
- Is it easily reproducible (e.g. “Magic motor” (1999))? Thus ensuring the students' success in the project.
- Is it cost efficient or at least affordable?

Do we understand the physical foundations of the phenomenon?

- Do we and the students have the required physics knowledge: the relations between quantities that lead to the phenomenon
- Do we and the students understand the necessary mathematics? For in-class activities the mathematics should be within the expected knowledge of the average student, at least for the basic phenomenon.

If we can assemble the device, reproduce the phenomenon, but do not understand its physical background, the learning benefits are limited and certainly not following the aims of the YPT method. For in-class YPT activities it is advisable that the teacher understands the core of the problem without further study. If the problem is such that the teacher does not immediately get a good idea of the basic mechanisms and the qualitative explanation, it is almost certainly too difficult for an average student.

Built in success

For in-class YPT activities, the expectations should be much lower than for the competition. So should the problems. Especially convenient are problems which allow for different levels of research, such as the example of the oscillator in Appendix 5. This enables engagement for all students and differentiation within the class. A very distinctive aspect of YPT compared to other inquiry-based or project-based approaches is the formal discussion with peers. So time should always be planned for some discussion.

If the problems are selected well and presented in an appropriate way (see Section 3.2 and Appendix 5), all students should be able to complete at least the easiest tasks, thus ensuring their success.

Time management

During the initial preparation, the physics teacher should correctly assess the time needed for the project. In our experience, a realistic time frame is based on **three 45-minutes sessions**. Detailed time management is presented in section 4 where a suggested concrete implementation is presented. Depending on the number of students in the class, it may take up to two lessons to present presentations or discussions. The method presented in chapter **'Discussion'** will enable our students to present, discuss and evaluate each other in only one physics lesson. It is advisable not to rush the activity. For successful project work, students should lead the activity, not try to catch up.

IYPT

For IYPT preparation, the vast majority of the 17 problems should be solved. Students or teachers sometimes have access to additional equipment, not suited for work in a classroom setting. Sometimes sponsors or institutions (universities, institutes) can be contacted to lend the equipment necessary or allow students to perform experiments at the institution. Students will also need a place to store the equipment, since the experiments will probably be performed over a longer period of time.

Students will mostly work on their own time. The teacher should be available at least from time to time to offer suggestions and check on the progress. Of course, the more the teacher is present, the more they can help the team and the better the chances for success.

The first step

When preparing for IYPT and IYPT-like competitions, it is important to keep in mind that this work is very different from traditional competition preparation and school teacher work. Open-ended research problems require different tasks and work organization than pen-and-paper problem solving or lectures.

Although a majority of the 17 problems should be prepared for the IYPT, with a little luck 12 might be enough. On the other hand, AYPT only requires three solved problems. So considering a few criteria when selecting problems even for competitions can greatly enhance the subsequent capacity for preparing solutions. **In addition** to the criteria for in-class problem selection, for competitions there are some additional criteria to consider.

Is the task experimentally feasible? This includes:

- Some students may have access to additional equipment or resources and can construct more complex apparatuses at home.
- It is possible to contact institutions (enterprises, universities) who may offer equipment and maybe even work space for students to construct and perform the experiments.

Do we understand the physical foundations of the phenomenon?

- We may not understand the phenomenon immediately. Are we prepared and able to learn the physics and mathematics behind the phenomenon? Good references are the "Reference Kit" or the website of the Canadian YPT team .
- If the mathematics are too complex, do we understand the basic physical principles enough to qualitatively describe the phenomenon and explain experimental outcomes or model the phenomenon numerically?
- If the mathematics are too complex, can we understand the basic process and underlying assumptions for deriving the result? Do we understand the physical meaning of the final

result and the role of various physical parameters and can we explain their role with words and basic physical principles?

If we realize that we either do not have access to the necessary equipment or we cannot foresee the students learning the physics at least to one of the levels described above, it is **not advisable to start working on the problem**. In many cases, the students´ interest will be driven to the most difficult task, but then failure is very probable, which is not preferable for either the student or the teacher. To avoid this, teachers should steer the students' interest towards problems that can be solved.

Contacting experts

If your experimental or theoretical work requires special tools or knowledge, do not be afraid to turn to experts! Many times, a single good practice or thought (literature suggestion) by an expert can save us weeks in the preparation. Try to build a base of contacts of accessible experts in basic fields of physics, including mechanics, electricity and magnetism, optics, gas and fluid dynamics. While specific subjects may be still needed, these are areas, which repeatedly appear in all IYPT tasks.

Time management

Investigating IYPT problems is a long term commitment. The students usually work in bursts when other school activities are less demanding. The teacher should take this into account. It is also helpful to give short term goals (one week or so) and check how well they were achieved. This keeps students working and the teacher involved up to date.

General

3.2. Tasks to perform

Whether doing an in-class activity or preparing for IYPT competition, the structure of the research process is the same. However, the level to which each step is elaborated differs drastically between an in-class activity and IYPT preparation.

General

The steps

I) **Initial observation:** Reproduce the phenomenon. Observe.

II) **Initial idea:** Generate an initial (naive) idea of the physics behind the phenomenon.

IIIa) **What to investigate:** From the initial idea get an idea of what might be the relevant parameters, how they might relate to the final outcome, and decide what to investigate further.

IIIb) **Planning the experiments:** Based on the decision what to investigate, design the experiment to carry out. This step emphasizes the design of the experiment.

IIIc) **Systematic experiments:** Make systematic experiments to investigate how the outcome depends on the chosen parameters. This step emphasizes the data gathering.

IVa) **Model:** Build a more sophisticated model of the phenomenon, capable of predicting the measured results.

IVb) **Model predictions:** Make predictions based on the model. Have clear expectations of what should be the outcome of the experiment, if the model is correct.

V) **Comparison model-experiment:** Compare your measured results to your model predictions. If they do not match, return to VI). Sometimes it is necessary to return to II) because the initial idea was not adequate.

VI) **Present:** Prepare a presentation of your process and your findings. The comparison model-experiment is crucial.

VII) **Defend:** Defend your findings against scrutiny. The purpose of scrutiny is to test the validity of the findings, not to undermine them at any cost. If the work is done well, it should be acknowledged. If it is done poorly, the shortcomings should be pointed out.

Steps III) and IV) are generally interchangeable, because they are independent. A model is derived from the physics underlying the observed phenomenon, while the experiment is an investigation of reality. Some students may choose to first do the one and some the other. **For some students, the naive idea in II) already serves as the model discussed under IV)**, because they will never refine the model and thus the initial idea will be the only model they have.

The most innovative part of the YPT method that sets it apart from other IBL methods is the **discussion** part during the defence of the findings. In YPT, the scrutiny is done **by peers**, not the teacher. This is important especially for the peers who have to activate a very particular set of critical thinking skills to adequately lead the discussion.

Each part is done to a different degree whether it is an in-class activity or IYPT. In the following we describe the levels expected in in-class activities and expand them in the IYPT parts. To keep better track with the schema above, we underline the steps that correspond to the above.

To keep the document shorter, we already **organise the in-class work into 20 minutes sessions**. Some sessions might be a little shorter and some a little longer, but the 20 minute segments allow teachers to better plan the activity based on how long their lectures are. This time management suggestion **does not apply to IYPT activities**, as they are much more flexible and require longer times.

General

3.2.1. Initial observation (I), initial idea (II) and what to investigate (IIIa) (first 20 min session)

In-class

- The students are put into groups – groups of two are preferable, but larger groups can be used if not enough equipment for the experiments is available.
- **Initial observation.** The teacher explains the experiment. The experiment can be shown in video, figures or as an actual experiment. It serves for the students to build the first naïve model.
- **What to investigate.** The teacher explains the objective. This can be the determination of a functional dependence on a parameter, or the analysis of the outcome of an experiment. This should be open enough so the approach is not obvious to the students, but clear enough so that they know what is required.
- **Initial idea.** Students subconsciously build a naïve model about the experiment. The teacher should encourage the students to explicitly state the model, even if it is only a partial model. It serves for the students to think about what could be the relevant parameters and what they could choose to measure.

IYPT

In addition to the above:

- **Multiple levels and approaches.** IYPT problems are typically formulated very generally and they permit a solution on a multitude of levels. It is common that different teams come with fundamentally different approaches. Students should think about various approaches to solving the problem: while they select a small subset for their own solution, they need to be aware of other approaches as well in order to succeed in the discussion.
- **Literature review.** For YPT competitions, acquaintance with literature is expected. It is a good idea to start by reviewing the literature first, as we often find articles that explain the phenomenon in detail. These usually include an experimental set-up to help you design your experiments. Dedicated sites and the internet generally provide a huge pool of resources. Students often get lost in the large amount of literature. Accordingly, the literature to be used should be filtered for them. Good sources for specific information are:
  - The "Reference Kit" and the Canadian team's website.
  - Wikipedia; search in the cited sources is strongly encouraged.
  - Journals like American Journal or Physics or Physics Education may contain relevant texts written in an accessible language.
  - Supporting texts for National Physics Olympiad.
  - A good source of general physics knowledge are Physics textbooks for more general public such as Physics by Halliday – Resnick – Walker. Survey of Applicable

Mathematics by K. Rektorys or equivalent. Despite the era of internet, students should have these resources available in the printed version, in order to have the possibility to browse in the books and obtain a broader background in physics and mathematics.

- **Originality of the research.** The question of how innovative the results should be is often asked. Especially in cases where a scientific article seems to cover the issue in its entirety. In the IYPT scoresheet there are also rubrics for "own contribution". We present what is expected as "new" in a YPT competition in Appendix 8.

General

3.2.2. Planning the experiments (IIIb) (second 20 minutes session)

In-class

- **Planning the experiments.** The students determine what they want to measure – which quantity they want to measure and which parameters they want to vary – and use the remaining time of the lecture to design the experiment they want to conduct – this can already be intertwined with building the set-up, if the lecture is longer than one hour. They should also decide on the measuring equipment (stopwatches, ampere meters, …). If they have time, they should also test whether the chosen equipment is capable of measuring the desired quantity (are the times long enough for manual triggering, are the currents large enough for common ampere meters…). The in-class experiments should be chosen so that the required measuring equipment is available.
- Expectations from the naive idea. Technically, these are **model predictions**, where the model is the naive idea). It is productive to have expectations already at this stage. Students often do not think of this, that is why their expectations, based on their naïve model should be explicitly stated. If the model is complex an idea about what will be the results is sufficient, if it is rather simple, a functional dependence can already be "guessed". It is very important that at this stage it is perfectly fine if the expectations of the student are wrong. It is very important to clarify that it is not the student that is wrong, but the model. The same student can come up with a better model. Reflecting on their expectations and their model will help students learn more from the experiment, as it confirms or refutes their expectations. We should be present to answer questions and help students with the design, but not the results.
- At the end of the lecture each group should have designed an experiment and formulated an expectation of the result of said experiment.

IYPT

- **Deeper thought to parameters.** It is best to list the parameters that determine the phenomenon before starting systematic experimental work, as it is worth designing and constructing our experimental set-up, so that most parameters can be varied. It is important to understand the exact wording of the problem! If there are clearly defined parameters, then you have to adapt to them (e.g. in the case of "Hot Water Fountain" (2016) you do not need to experiment with glycerol), but the parameters listed in the problem should be examined. Note, that it is not possible to build the perfect equipment at first. It is possible (and usually necessary) to develop it through experimental work as a pilot project and incorporate new, unexpected influencing factors. Never forget to detect and quantify experimental errors!
- **Existing, borrowed or new apparatus?** Start from the simplest available equipment. If needed, think how to obtain more detailed and more accurate results – this means not only better or more sophisticated instruments, but also analysis of conditions under which better/more illustrative experiments can be performed. Some unavailable equipment can be built by skilled students, or accessed at academic institutions. Sometimes less is more.

General

3.2.3. Systematic experiments (IIIc) (third 20 minutes session)

In-class

- The students build the experiment.
- **Swiping the dependence.** It is advisable to first perform just a few measurements over the entire range of the selected parameter (swipe). This serves to see if the results are measurable on the entire range (they do not overshoot or undershoot the range of the measurement equipment), and to determine which parts of the range require more fine measurements (rapidly changing result) and for which parts coarser measurements suffice (slowly changing result).
- **Systematic experiments.** The students start with the systematic measurements. They should be aware that careful and precise measurements will be key for later evaluation. However, students should not be given instructions on how many measurements to take. Instead the guidelines should be: "take enough measurements to identify the functional dependence" or "determine the error of each measured point". Students should have learned gradually by doing this type of experiments how many measurements are sufficient to achieve these goals. When extracting parameter dependencies, it should be left to the students to decide how many data-points are required. This depends on the time required for each measurement. In general, **3 points** are minimum to identify the **functional dependence** and **3 repeated**

- **measurements** are the minimum to determine the **experimental error**. Although between 6 and 10 measurements for each point would be recommended.
- Students should keep in mind that for the majority of problems the ultimate goal is to compare the measurements to the model predictions. A perfect match is not to be expected so the margin of error is crucial to judge how well the two match.

IYPT

In addition to the above:

- For IYPT, it is generally not sufficient if just one parameter is investigated. Ideally, **all viable parameters** should be investigated at least superficially, while two or three should be investigated in detail.
- **Reproducibility.** Always check whether a measurement is reproducible within an experimental error. Think about possible influences which limit or prevent the reproducibility.
- Whenever possible, verify that the results are meaningful and at least internally consistent.
- Try to verify the performance of your apparatus using a system with well-defined behaviour and properties. If in doubt about measured results, do not hesitate to retry the verification.
- Remember to measure not only the target quantity, but also the parameters and conditions important for the experiment! It is a pity when results of a lengthy measurement must be discarded just because nobody remembers a single trivial parameter. Students should keep a log of all measured data. They may come in handy at a later time.
- Students should be advised to always try to seriously estimate the errors (confidence interval) of measurements. The role of errors is to determine to which extent we can trust the measurements. And as such they are fundamentally important in the comparison with the model. Error bars typically represent random errors combined with declared measurement errors of a device, but there may be further systematic errors, which also compromise the results. In certain cases of difficult measurement, only a qualified estimate of an error may be available (see Appendix 5, line 12).

General

3.2.4. Model and model predictions (IV) (fourth 20 minutes session)

In-class

- **Model.** Students should build a proper model. They should start from basic physical laws governing the phenomenon and arrive at a model for how the quantity they measured depends on the quantity they varied. Depending on the difficulty of the problem and the skill of the students, this model can be:

- Qualitative: describing with words, what should affect the outcome, why and how (increase the result, decrease the result, ...). The initial naive idea can sometimes serve as the qualitative model.
- **Quantitative:** deriving an equation for the result depending on the investigated parameter.

- **Model predictions.** Based on the model, students should make a clear prediction of the expected results. If the model is quantitative, a quantitative expectation should be produced, usually in the form of a graph to compare to the measured data. Depending on the data, other representations might be more suitable (table, sketch, animation).

The tasks in the fourth 20 minutes session can be done at home, but cooperation of the entire group in building the model is encouraged. It may be that some students are more theoretical and some more experimental, but group work is an opportunity for the students to learn from one another especially the facets that they are less comfortable with. In this case, the fourth session can be used to continue the work from the third session.

IYPT

There are different types of models. See Appendix 3. For IYPT competition, different levels of the model are expected for problems of different difficulty.

- **Analytical quantitative model**. For IYPT problems, the models are often available in literature and sometimes too complex for students to be able to reproduce the derivation. However, in any case students should be able to:
  - i) Students should be able to explain the dynamic equations of the system. This means the fundamental physical laws that govern the behaviour of the system. A combination of these laws is usually the path to the final result.
  - ii) Students should be able to justify the steps taken in the derivation. This means how they related the various dynamic equations. If they can reproduce the derivation, even better.
  - iii) Students should identify the assumptions made and critically assess whether they are applicable to their own experiment. Sometimes the literature treats a somewhat different problem, which is very similar, but might have different circumstances and thus different assumptions.
  - iv) Students should be able to explain the role of the various parameters in the final equation and their physical origins and meaning. For example: “The first term derives from the [...] law. The coefficient in the second term represents [...]. The third term in the denominator is negligible, if [...]” and the like.
  - v) Even if the students are able to reproduce the entire derivation, they should skip it in the presentation, and rather focus on the items in this list. For the jury it is difficult to follow a sophisticated derivation, if they are unfamiliar with it, and most will appreciate a physical explanation of the derivation more than a rigorous derivation.
- Numerical quantitative model. If the dynamic equations are understood, but the derivation of the final result complex, students may produce a numerical model

(simulation). In this case students need to be able to explain points i), ii) and iii) above. Instead of points iv) and v) it helps if the students are able to explain the result of the simulation. Something like: "It is reasonable, that the curve starts to decrease at [...] values, because at that point [...] happens."

General

3.2.5. Comparison model-experiment and preparing the presentation (V) (fifth 20 minutes session)

In-class

These are two very important parts of the process. However, for an in-class activity, they should not take long. The model should be simple and the presentation also. It could be done on whiteboards during the process itself. Nonetheless, the most fundamental elements of the two steps must be done well.

Comparison model-experiment

- Students should analyse the data they generated, which includes estimating the errors.
- Students should present their data in a form that can be compared to the model prediction. Usually, this will be in the form of a graph where the data are plotted as points with error bars and the model prediction as a line. It is important that they label the axes and the units.

Preparing the presentation. The presentation should include:

- The initial observational experiment should be described or shown.
- The goals (research questions). A short declaration of what the students tried to achieve, measure, determine.
- A quick description, sketch or picture of the experimental setup.
- A description of the model. It suffices if the starting dynamics are given and the process of derivation is quickly explained. The detailed derivation should be skipped. For in-class activities the derivation should be simple enough for most investigated parameters. Only the most advanced tasks could be expected to have a demanding derivation.
- The comparison between measured data and model prediction. This usually means plotting the "theoretical" curve over the data, or using some other representation (comparing tables, comparing effects), if more appropriate. This is very important! This is the arbiter of how good the explanation is, and the explanation is the goal. So the arbiter of how well the goal has been achieved is the comparison between measurement and model.
- A conclusion: a clear answer to the research questions.
- The teacher can pose questions that can serve to guide the students towards important findings, and these questions should be answered in the report.

The tasks here can be left to do at home. It depends on what students are used to. In some countries, homework is common and students are used to doing it. In some countries homework is strongly discouraged or very unusual. In some countries it is allowed, but students can be neither penalised nor rewarded for homework, so most students will not do it. In such situations, this part can be done in school. We strongly suggest using whiteboards (A3 or A2 format, laminated paper works fine). Whiteboards allow students to make on the fly presentations while gathering data. The same can be achieved in strongly ICT supported environments by making students design presentations on the fly. The details in a class setting are less important than the process. The students can focus on what to present, how to present it and not so much on the detailed accuracy of the data and graphs. If done at home, more sophistication can be expected.

IYPT

For IYPT, the same basic structure is expected with the following modifications:

- The description of the experimental setup should be very detailed. Additional slides on the setup can be included as appendices for the discussion. Sometimes the smallest things matter, such as how did the students make the device as horizontal as possible.
- The description of the model should include everything listed in the section about the model, but not the entire detailed derivation. This can be included in the appendices for the discussion.
- The comparison model-experiment should be detailed and carefully done. Error estimation is crucial.
- Any discrepancy in the comparison model-experiment must be analysed and discussed. It is expected that students provide an explanation for the discrepancy. It can also be a topic for the discussion.
- The role of the conclusions is not to summarize the work done, but to actually conclude something from the research, such as: “Based on our research, the phenomenon is due to [...]”. It is best to clearly formulate the research questions and as conclusion give clear answers to the research questions.
- It is advisable to number the slides for quick reference.

Students often measure huge amounts of data during their work; it is then sometimes difficult to persuade them that only the important results should be presented while throwing out many data which required many days to be measured. Students should use only data that can provide the answers to the research questions. Emphasis should be put on how to reduce the number of data while extracting pertinent information.

A graph often summarizes the student’s work during several months; appropriate care and time should be thus devoted to the construction of the graph. Pasting raw data to any software may produce disastrous results without further editing. Graph is easier to read in oral presentations, use tables with care. Most graphs are of the XY-type; some other graphs like histograms, contour plots, or polar plots may be also useful in certain specific situations. Use non-standard graphs with great care, the results may be sometimes difficult to read.

Students should take care to label axes (including correct and reasonable units) and display labels understandable to a broad public. Think about axis type (linear, logarithmic, other), usefulness or displaying important points (namely 0), axis range and step.

Symbols should represent sparse data (typically experimental results), while lines should be used for data representing a continuously varying parameter (typically theoretical predictions or fitting curve). Different data should be clearly distinguishable (colour, line style, symbol style). For graphs with many data sets, mnemonics should be considered (e.g. use blue colour for data measured at low temperature and red colour for data at high temperature).

General

3.2.6. Present (VI) and defend (VII) (sixth, and any additional 20 minutes session)

This section is very different for in-class and IYPT activities, but the purpose is the same: **critically assess the report**. The term "opposition" used in YPT jargon is misleading as it implies a contrary opinion at any cost. Instead "critically assess" ("oppose" in YPT jargon) means give praise where praise is due and challenge what does not convince you, as well as state disagreements and mention what has not been explained clearly enough.

The critical assessment of reports is arguably one of the most important skills of the 21st century for the general public. Be it news reports, reports of scientific or pseudo-scientific findings, marketing adds, or various schemes. And this is the part that is most innovative and identifiable in YPT activities. As such it should be given an appropriate emphasis.

Keep in mind that:

- A good guideline is to **help the presenter** modify their report or research in order to make it better and more convincing.
- This should be a **discussion**, an exchange of **explained** opinions, not a mere questions-and-answers session.
- It should also allow the "opponent" to show their own understanding of the physics underlying the phenomenon.

In-class

Given the aforementioned importance for the general public and for the understanding of the epistemology of science, the opposition part of the YPT process should be given an appropriate emphasis in in-class activities.

Here are the most useful questions to think about as a peer reviewer (opponent in YPT jargon) of the report:

- Which parts have not convinced you? Do not think that you probably should have understood and that somebody else in your place would have understood. You are the peer reviewer and if you do not understand or are not convinced, ask.
- Do the conclusions really follow from the data? Is it not possible to reach any other conclusion? For example: if there are three measured points with experimental errors presented and a straight line is drawn through them, is the straight line really the only option? Could a parabolic line fit the points equally well? If so, what is the justification for choosing a straight line instead of a parabolic one? This allows the opponent to present their own opinion.
- Ask fundamental physics questions related to the presented model. Questions like: "What do you think would happen if instead of [...] we used [...]?" This allows you to show your own knowledge of physics. Especially if you disagree with the reporter. Always indicate whether you agree with the reporter or not. If you disagree, provide your own answer. This type of question might provide some of the best topics for discussion.
- Was the setup appropriate? If you are in doubt about any part of it that you find relevant, ask questions and specify why you find this important. For example, a measurement of a cannon's range depends on the initial angle of the cannon. If the reporter has not explained how they assured the horizontality of the cannon, ask.

There are different ways in which the presentation and discussion can be handled in an in-class activity. We present two:

Method "Share good practices" (SGP)

- Only the best 2 teams/groups present based on their report in the fifth session.
- The two second-best teams oppose them.
- The rest of the teams make reviews.
- Report/presentation (8 minutes), so we still can have time for the discussion, review and short teacher feedback. In practise, it is recommended to let every member of the reporting team say some words during the presentation, but the teacher is free to differ.
- Opposition and Discussion (1+2+3 minutes). Based on the prepared presentations the 3rd and 4th teams can oppose the presentations of the reporters, whose role can also be rewarded with extra points. The following points/steps show a sample script of the opponent team:
    - Evaluation during the presentation: The members of the opponent team observe and evaluate the report with the help of the opponent template (see Appendix 10).
    - Preparation: After the report the opponent team has 1 minute of preparation time to organize their thoughts and to send their "spokesman" to the "stage" in the front of the class.

- Summary: The opponent begins with a 2-minute summary and evaluation of the presentation of the reporting team. At this point no computer is needed and using the opponent template is recommended.
- Discussion: Next comes the 3-minute discussion with the "spokesman" of the reporting team, asking concrete questions to the reporter who tries to answer the questions.

- Review (2 minutes): During the presentation of the reporting team and the discussion, the members of the reviewer team – or eventually teams – observe and evaluate the performance of the two teams using the reviewer templates (see Appendix 11). In case of only 1 reviewer team (in smaller classes) the reviewer team has 2 minutes (in case of 2 reviewer teams only 1 minute each) to evaluate and name their winner of the "fight".
- Teacher's question and short feedback (max. 4 minutes): It is also worth taking the time to answer teacher's questions, as students may overlook many aspects or even serious errors that need to be corrected. While students are being evaluated, the technical preparation for the second "fight" can take place.

Using this recommended scenario physics teachers are going to be able to conduct a "fight" within only 20 minutes, so there is time for a second one within one 45-minute lesson. To make opposing and reviewing easier we can use the opponent and reviewer templates (see Appendices 10 and 11). Because of the shortage of time we reduce the reports only to the best teams according to the following simple method: on the last lesson before the reports we collect all of the presentations (e.g. PPT files) from the teams. Before the presentation session we select the two best teams (the decision is announced at the beginning of the presentation lesson), who get extra points for their success. Beside the time aspect it is also useful that we only spend time on the best presentations, so the students can see good examples, but the whole time all students are active participants in the lesson.

Method "All Groups Report" (AGR).

- One team presents their findings using whiteboards, posters or a short slideshow (in ICT strong environments). They have 3 minutes. It suffices to present the most important findings in the following form:
  - The research questions and a sketch of the apparatus and the measurement equipment (30 sec)
  - The model (qualitative or quantitative) (1 min)
  - The data, the comparison (1 min).
  - The conclusions (30 sec)
- Another team opposes asking questions (5 minutes). Our suggestion is to ask "what if" questions, adding their own opinion after the answer of the presenter, thus sparking a short discussion if there is disagreement. Just one question is enough, especially if more

than one fight is intended. A few examples of questions based on the falling magnet example would be: “What if the pipe was nonconductive?” – shows understanding that currents are crucial. Or “What if the pipe had horizontal slits?” – shows understanding that the most important currents run horizontally. Or “Would you feel the force if you lowered the magnet really slowly through the pipe?” – shows understanding that the eddy currents depend on the change of magnetic field. This kind of questions can show the physics knowledge of both the reporter and the opponent.

- The review is done by all the other teams based on the rubric in Appendix 12. The reviews are collected and the winner can be decided based on the average score.

It is recommended that in-class projects are not too difficult. Moreover, they should allow multiple parameters to be varied. This way the reports are interesting for many teams as they investigated different parameters.

Using the above format 10 minutes should suffice for one “fight”. In such a short time it is difficult to get good questions, but this can improve with practice. The teacher can gradually modify this time based on experience and decide that only randomly selected groups will report. If the YPT format is used several times in a year, all groups should get a chance to report, and the quality of opposition will improve.

IYPT

3.2.6.1. Presentation

Guidelines for the preparation of the presentation are given in previous chapters, so we will not repeat them here. The only very important additional element for the presentation itself is the clarity of speech. This includes appropriate loudness and adequate English. The English does not need to be perfect, but students should look up the English terminology and the pronunciation of unfamiliar words. An interesting example is the word “momentum”, as some languages use a similar word to refer to “torque”, and some languages use “quantity of motion” to refer to “momentum”. Using the wrong word can cause unnecessary confusion.

3.2.6.2. Discussion

Discussion is perhaps the most critical point in a fight. Even after an impressive performance of a reporter a good opposition can modify the jury's positive image of the report and can significantly decrease the points of the reporter and increase the points of the opponent. It should at this point be noted, that there is no definite text-book approach to the opposition at the IYPT. First this is because different problems ask for different discussion and most importantly because reports vary in direction, depth, quality and focus. Thus, also preparing generic questions might not be the best idea. Instead **preparing a basic understanding of the physics** involved in the task, as well as what parameters will probably be important and should be looked at is advisable.

The opposition part is divided into four phases: clarifying questions, opponent's speech, discussion, and opponent's summary. In the following, recommendations are given for both the reporter and the opponent for each phase.

3.2.6.2.1. Clarifying questions (2 minutes)

Opponent's clarifying questions: The purpose of the questions is to provide the opponent with a solid summary of the presentation. Accordingly, the aim of the questions is not examination, but to clarify issues that were not fully understood.

- The questions should focus almost only on the work done by the reporter.
- Ask questions about methods and clarify points which may not be evident to the opponent or the audience.
- Ask about justification of assumptions, if they are not stated clearly.
- Ask if they did X, but do not go into detail.
- Do not ask very specific questions.
- Do not start a discussion about parameters or similar. These questions should be simple clarifying questions and not a discussion.
- It is worth asking the questions in order of importance. Ask questions about theory, experimentation and evaluation! (Unless one part is severely defective)
- Allow up to 30 seconds per question. If the reporter gets lost in a long answer, thank her/him politely and go for the next question! You can continue the issue later in the discussion section. A short yes or no answer is difficult to get for too detailed/voluminous questions, so one may rather skip them for the discussion!

Reporter's responses to clarifying questions: The role of the reporter in this is to answer the questions.

- The answers should be clear and concise. It is advisable to prepare in advance for the possible questions.
- If a question demands a more detailed and lengthy answer, the reporter should attempt to answer it anyway as clearly and concisely as possible. As explained above, it is the job of the opponent to stop the reporter and transfer the question to the discussion, if necessary.

- It is worth knowing our slides so that the appropriate slide can be quickly found, if needed.

3.2.6.2.2. Opponent's presentation (maximum 4 minutes)

The purpose of the presentation is to summarize the most important results, to evaluate the problem solution, to highlight the good and bad content both in theory and experiments.

- The opponent should give a critical summary of the report showing his/her understanding of the main parts of the presentation.
- The good things should be highlighted (with proper justification). Don't be afraid to praise a good performance!
- The opponent should point out the shortcomings of the report. Focus first on what has been done, but could be done better, and only then on what else could be done that has not been done.
- It is worth highlighting whether the problem statement has been fully met. Each missing point is to be explained carefully.
- The opponent should open the points for discussion.
- The quality of the presentation and the quality of the slides should also be evaluated.

3.2.6.2.3. Discussion (10 minutes)

Opponent's role: During the discussion, the opponent should have a detailed dialogue with the reporter about the issues that they find relevant regarding the reporter's solution and understanding of physics. The opponent's purpose is to facilitate a polite but efficient discussion and to deliver an honest and detailed scientific critique in order to **develop further the reporter's solution to the problem**.

- Focus on the work of the reporter. A good discussion will use the report as a basis and explore physics beyond what was presented or uncover flaws and shortcomings. However, even if the reporter's theory or experiment was severely flawed the discussion should remain constructive and focus: identifying the flaw, clarifying what went wrong, developing a solution to the problem – or an Ansatz to the solution.
- If the report was strong, discuss possible extensions of their theory or experimental work. Discuss what might have been interesting to look at even further and what might happen if we change x/y.
- If a report presents inconsistencies, e.g. contradicting approximations or inadequate approximations, this is often a good point to start the discussion with.
- Focus on essential points, prioritise the topics, do not get stuck in simple formal, theoretical or experimental details.
- Formulate short and clear questions and use simple language throughout the discussion. Linguistic difficulties may lead to an inefficient discussion.

- If the reporter does not know the right answer, under no circumstances start lecturing. Always be calm and polite, try to lead the reporter on the right path. If you do not succeed, close the topic and move on!
- After discussing each point, it is worth pausing and summarizing the outcome of the discussion in a few words. Highlighting your own opinion on the matter is always of utmost importance. If an agreement was reached with the reporter, do not be afraid to make it clear.
- Do not bring in your interpretation of the problem or your solution! If there is strong reason to believe that the reporter clearly did not fulfil the task this should be noted, but the discussion should still focus on the report, or how physics might turn out if the experiments were conducted as intended.
- The opponent should under no circumstances make arguments like: “Your results must be wrong because when we did experiment x, we observed y which disagrees with yours.” If you can bring a strong physical argument why the explanation of the report is probably incorrect this is fine and should be done, however since nobody saw the experiments of the opponent, or could check their validity, they should also not be used as an argument.
- If the opponent has their own model, which disagrees with the model of the reporter, they should identify the possible crucial steps that potentially led to the disagreement and use the discussion to talk about them, focusing on the reporter’s model, not the opponent’s. Example questions: “Why did you choose to use this set of fundamental laws?”, “Have you considered any other law(s) when building the model?”, “I can think about [insert a law here], have you considered it? Why not?”, “Can you please explain why you decided to do [one particular] step?”, etc.
- When discussing shortcoming of the report a common mistake is to focus on irrelevant physics. For example, it is not adequate to mention the neglecting of air resistance as a flaw in the falling magnet problem. The opponent should have a sense of what is important to the task and what can – and maybe should – be neglected.
- If the reporter asks a question, the opponent should answer. This is a discussion, not a question-and-answer session. However, the opponent should lead the debate.

Reporter’s role: During the discussion, the reporter must defend their solution and prove their objective knowledge of the subject.

- It is important that we fully understand the question. If something is not absolutely clear, you can ask the opponent for clarification or ask your team for help. It is very counterproductive to get involved in a debate that is based on misunderstanding.
- The reporter should align the answer to the scope of the question and be as clear and concise as possible. If the opponent is satisfied with the answer and does not pursue the topic further, they should move on to the next question.
- The opponent should lead the discussion and they can stop the reporter, if the discussion becomes off-topic, unnecessarily long or unproductive. However, if the reporter feels that

some key explanation is still missing in the answer, they can politely ask the opponent to let them fully answer, but their answer should be as concise as possible.

- Do not be afraid to ask the opponent if they do not share their opinion (e.g. "Why do you think this is important?" or "What is your opinion about this question?"). It is often the case that the opponent fires blindly, and the reporter can expose this, by asking the opponent for their own opinion. In addition, in a real discussion both parties must have the right to ask. However, the opponent should lead the debate.
- Remember that at the end of the fight the reporter still has 2 minutes to clarify his position and to respond to any unsubstantiated criticism.
- It is worth knowing the slides of the presentation and having them numbered so that one can jump straight to the appropriate slide when needed.
- It is advisable to anticipate the possible questions of the opponent (asking oneself, how one would oppose one's own presentation). It is advisable to prepare slides with the answers to these possible questions. This includes slides with any auxiliary data or results that might be relevant in the discussion.

3.2.6.2.4. Discussion Summary (1 minute):

This part is very important! Here, the opponent's goal is to give a general summary of the discussion and presentation. Keep in mind that afterwards the opponent will only have a chance to speak when answering any questions.

- Only essential parts should be highlighted, not elaborated.
- It is worth highlighting the most important positive result, but also the biggest shortcoming and the most serious topic of disagreement.

3.2.7. Review

The goal of the review is to pass judgement about the research. The reviewer should have carefully listened to the presentation, the opposition and the discussion. Their job is to evaluate them and give a judgement: who was more convincing, how well the reporter defended their findings, were they prepared to accept criticism and admit if they made mistakes, how relevant were the questions of the opponent, did they contribute anything to a better solution or a better understanding of the solution, etc.

In-class

The suggestions on how to perform in-class reviews differ. In both suggestions given above, the reviewer evaluates both the reporter and the opponent.

- In the SGP method, they name a winner and provide a short justification for their decision.
- In the AGR method they grade the reporter and the opponent on rubrics and the teacher can use these results to name a winner.

In the in-class format, the review is not given strong emphasis, but it provides an opportunity to engage students who are not the reporter or opponent. The limited time in class is better spent on the discussion.

IYPT

Part of the Reviewer's job is similar to Opponent's critical analysis but requires covering many more topics within the same time. So, being concise, articulate and focused on the key features is even more important here.

In YPT competitions, the reviewer gets three opportunities to earn points: asking questions, evaluating the entire process, and giving judgement or own opinion. The reviewer is supposed to show their own understanding of physics while not being able to enter a discussion. As a "rule of thumb", the reviewer should do what the jury would like to do. Good grades are typically given when the reviewer addresses the points that the jury feels should be addressed.

Reviewer's questions: The reviewer should have followed the entire process carefully and should use this time to address issues which were not made clear enough or where their opinion differs from the reporter's, the opponent's, or both. Here are some types of question that the reviewer can ask:

- Ask for justification for a particular decision, if it was not given. This shows that the reviewer understands the physics and was able to spot that a justification was not given.
- Ask for the opinion of the reporter or opponent on a particular topic, if it was not given. Sometimes the opponent asks questions, but does not give their own opinion on the answer. In these cases, the reviewer can show that they followed the discussion and identified the shortcomings.

Reviewer's evaluation and judgement: The reviewer is supposed to give an evaluation of the presentation, the opponent's speech and the discussion. At the same time, they are supposed to give their own opinion on the essential topics. The usual strategy is the following:

- Evaluate the research done by the reporter, emphasizing its strengths and shortcomings.

Some reports may have a strong experimental basis, but a poor theoretical model and some may be the other way around. Most reports are in the middle, so the reviewer should carefully consider which points are done well and which are lacking and what has remained unclear. The reviewer should **give judgement on the validity of the conclusions.**

- Pass judgement on the task fulfilment by the reporter and its evaluation by the opponent. Did the opponent correctly evaluate the task fulfilment of the reporter.
- The reviewer may give their own opinion on how the report could be improved.
- Summarize the opponent's speech. This mostly consists of the opponent's identification of strong and weak points of the report, and an evaluation of whether these strong and weak points have been pointed out also by the opponent. The reviewer may disagree with the opponent and may defend the reporter, if they find the critique unsubstantiated. They may also address points that the opponent missed.
- The reviewer should note all essential points of the discussion and indicate their opinion about each of them. Especially, all points of disagreement should be addressed and the reviewer's position on each of them clearly stated.
- The reviewer may qualify the discussion per se, for example they can express their opinion whether the discussion was useful for clarifying the report and went deeper into the physics involved or whether it did not contribute much in this aspect. Or whether it was interesting or boring; or whether it tackled important/relevant topics or wasted most of the time on minor details etc.
- It is a good practice to point out essential aspects of the problem (if any) which were not present either in the report, or in Opponent's analysis or in the discussion. The reviewer should specify why they find them important.
- The reviewer should give their opinion on the presentation, how convincing it was and how well did the opponent check its validity.

4. Conclusion

We have arrived at the end of the toolkit. We have tried to condense the information necessary to implement an in-class YPT activity and to prepare students for IYPT competitions. There is much additional information, which we decided to move to the appendices. The structure of the toolkit is such that the main part should be sufficient and brief, like a handbook, to use every time one prepares a YPT activity. The information in the appendices, on the other hand, are of a different nature. They explain parts of the process, but once internalized do not need to be reread every time one prepares a YPT activity. Therefore, we removed them from the main part.

We wish you good luck with in-class and/or team preparation YPT activities!

Appendices

Appendix 1: Research supported evidence of benefits of engaging in open-ended activities

Several works indicate broad benefits for students by engaging open ended scientific educational activities. In [1] the authors have interviewed 61 scientists and teachers specifically on the influence of IYPT on high school students. The answers confirmed positive effects on obtaining skills for future work in science, communication abilities as well as collective problem solving skills.

In [2] a survey on successful Slovak scientists was performed to learn main factors that influenced their interest in science in elementary school, high school, university and PhD study. Scientific competitions, together with the quality of the teacher, showed to be the main ones.

Miroslava Urbašíková in [3] and [4] interviewed more than 100 former Slovak IYPT and IPhO participants from 1998 to 2004, to ensure all of them are already placed on the labour market; more than 75% worked in science. She also applied YPT elements in standard physics classes and showed it helped the development of curriculum based competencies.

[1] Kluiber, Zdenek; Stanisic, Tomislav; Skocdopole, Vaclav: The Future is influenced by the Gifted. Orbis, Praha 2008, ISBN: 987-80-902616-0-0
[2] Pišút, Ján: Vzdelávacie cesty špičkových vedcov na Slovensku. Československý časopis pro fyziku. ISSN 0009-0700. Sv. 62. č. 5-6 (2012). s. 472-476
[3] Urbašíková, Miroslava: The Impact of a Development of Ability to Science Process Skills on Choice of Career in Science. Proceedings of conference „DIDFYZ 2016“, 19.-22.10.2016, Račková dolina, Slovakia
[4] Urbašíková, Miroslava: Spôsobilosti vedeckej práce v súťaži Turnaj mladých fyzikov. PhD thesis. Faculty of Mathematics, Physics and Informatics, Comenius University, Slovakia, 2017

Appendix 2: Types of experiments

Experiments in science have different purposes. It helps to identify the type of experiment, because it helps identify its purpose and therefore its goals. In the ISLE approach the experiments are classified as observational, testing and application.

- **Observational experiment.** The purpose of the observational experiment is to come to an explanation for the observed phenomenon. The steps are usually the following:
  - **Observe** a phenomenon or dependence.
  - **Propose a model** (explanation) for the phenomenon. See Appendix 3 for a discussion on the types of models. A simple explanation of the phenomenon in words would be classified as a qualitative mechanistic model.
  - It is important to keep in mind the **assumptions** made when proposing the model.
- **Testing experiment.** The purpose of the testing experiment is to test a model. Testing a model always involves comparing the predictions of the model to the results of an experiment. The steps are usually the following:
  - **Propose a testing experiment.** There are two subtypes of testing experiments.

        - **New experiment**. This is the strongest type of testing experiment. This should be a completely new experiment that is different from the observational experiment. A successful prediction shows that the proposed model is transferable to other contexts and situations.
        - **A systematic reproduction of the observational experiment.** The goal of this subtype is showing that the proposed model does indeed explain the outcome of the observational experiment. It is usually performed when the model prediction or the outcome of the observational experiment are so complex that an immediate match between the two is not obvious. It is also the subtype usually performed in YPT problems.
        - **Extending the range of parameters** outside the original range is a testing experiment, which is a mixture of both types.
    - **Make a prediction** about the outcome of the testing experiment based on the model, i.e. if the model is correct and we perform the [testing experiment], the outcome should be [model prediction]. Predictions should be made before the experiment is performed to avoid confirmation bias, but with appropriate discipline, they can be made after the experiment, when it is clear, which experiments will be compared with the model.
    - **Perform the experiment.** Log the data.
    - **Compare** the outcome of the experiment to the predicted outcome by the model. Make the appropriate data analysis to compare the two. Include experimental uncertainties.
    - **Evaluate the model.** Does its prediction match sufficiently well with the experimental outcome?
        - **If they match**, tentatively accept the model.
        - **If they do not match**, check the assumptions.
            - **If they are justified**, reject the model. This might differentiate between various proposed models or it may require the construction of a completely new model. Repeat the process with the new model.
            - **If they are not justified**, change the assumptions and make a new prediction based on the model. Repeat the process with the new prediction.
- **Application experiment.** Application experiments serve to solve a concrete problem. In YPT, problem *Invent yourself* is usually of this type. The goal of the application experiment is using the known physics to solve a practical problem, be it measuring the value of a constant or parameter, such as the gravitational constant, heat capacity, moment of inertia etc. or invent a device that serves a specific purpose such as a seismometer, a thermometer, a random number generator, etc. The steps are usually the following:
    - **Identify the knowledge** of physics required to solve the problem.
    - **Design the device/procedure** and perform the task.

- **Evaluate the performance** of your device/procedure. Find an independent method to test the performance of your device/procedure. This involves comparing the result of the device/procedure with a result from an independent experiment, or if an independent experiment cannot be reasonably expected, the accepted value in literature.

Appendix 3: Types of models

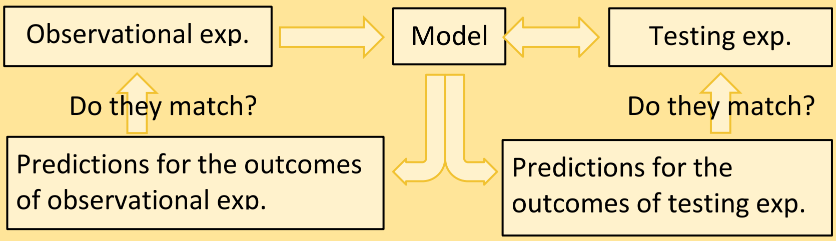
Model. The broad meaning of "model" is something that can predict the result from the input parameters. There are various types and levels of models.

- **Phenomenological model**. This type of model describes the dependence between two quantities without attempting to explain it.
    - The lowest level is just determining whether it is a rising or falling function.
    - A phenomenological model usually includes a mathematical shape of the function (exponential, polynomial, sinusoidal...). This shape is guessed from the data and is not based in any physical relation or derivation
- **Mechanistic model**. This type of model includes a cause-and-effect relationship between quantities. Here are the main types relevant for IYPT.
    - **Qualitative model**. Students understand the basic dynamics on a descriptive level. They are able to explain how the parameter affects the system and how this affects the measured quantity. But they are unable to produce a mathematical model that relates the parameter to the measured quantity. This model is capable of predicting the behaviour of the observed quantity in terms of "increase" or "decrease" and similar. For very difficult problems, this might be the best that can be reasonably expected from the students.
    - **Numerical quantitative model**. Students understand the dynamics and can describe it in mathematical terms, but an analytical derivation of the final result is too complex for students (nonlinear differential equations, non integrable functions...). In such cases the time evolution of the system can be modelled numerically from the dynamic equations. The result of the model can be used as the prediction and is usually in the form of a graph or simulation.
    - **Understanding the existing quantitative model**. For some problems, the model is already derived in literature and too complex to reasonably expect students to repeat the derivation. In such cases, it suffices that students are able to explain the final result. This means: identify the dynamic equations, the assumptions and understand the reasons for the steps taken in the derivation. Finally, students should be able to explain the role of the parameter in the final result, justifying it with the initial dynamic relations.
    - **Analytical quantitative model**. Students propose the dynamic equations and derive the final result. This model is usually given as an analytical equation (function) relating the investigated parameter to the measured quantity.
- **Assumptions**. A model consists of physical laws, mechanisms, such as Newtonian laws,

Lenz's rule etc., and assumptions, such as no air resistance, adiabatic change, constant pressure, etc. Sometimes a rule is only valid as long as the assumptions are valid (for example the equation for the magnetic field of a long solenoid - it has "long" in its name to remind us of that). If a model fails, it may be due to the assumptions not being valid rather than the wrong laws being used. A typical example are ballistics when air drag is not negligible.

Appendix 4: A little more on testing experiments

Observation, model, test. Observational experiments serve to build a model (explanation, equations). Testing experiments serve to test the model. In research the three are often intertwined, as described in Appendix 2:



Below are examples of the two subtypes of testing experiments and a short discussion on when each subtype is appropriate.

Examples of the use of testing experiments. In our experience, the testing experiment is least understood, so we provide here a couple of examples, one for each application of the testing experiment.

Example: falling magnet.	
Observation:	A magnet falls slower inside a metal tube.
Explanation (qualitative):	The magnet induces circular currents above and below itself which exert force back onto the magnet via Lenz's law.
Testing experiment: (Subtype "new")	Cut a slit in the pipe preventing circular currents.
Prediction based on the explanation:	The currents can no longer run, the magnet will fall faster or not be delayed at all.
Outcome:	The magnet falls faster.

Evaluation:	The prediction agrees with the outcome. There are still some currents that can run, which cause the effect, but the effect is diminished.

Example: Spring oscillator	
Observation:	The oscillation period increases with mass.
Explanation (quantitative):	The same springs produce the same force, so the larger mass means a smaller acceleration. Travel time is proportional to (the root of) acceleration. So the period increases as the mass increases. $t_0 = 2\pi\sqrt{m/k}$.
Testing experiment: (Subtype "repeat")	Measure the functional dependence between mass and period. (This is technically the observational experiment again, but going into details systematically and having a model to compare the result to, makes it a testing experiment.)
Prediction based on the explanation:	The dependence should be square root-like. Linearized: $t_0^2 \propto m$.
Outcome:	The dependence is square root-like. Linearized: $t_0^2 \propto m$. Note: this is, of course, assuming the parameters remain within the Hooke regime. Extending them outside this regime could be an advanced task for advanced students.
Evaluation:	The prediction agrees with the outcome. The values of the fitted coefficient can then be compared to the value of the spring coefficient k.

When is a new testing experiment required?

In YPT a systematic measurement of the observational experiment is an appropriate testing experiment when:

- The results of the observational experiment are complex. Typically, a dependence that cannot be explained by a simple mathematical function.
- The model provides a complex equation, for which visualization is not trivial. Typically, a mathematical expression composed from many simple expressions.

In both cases, matching the model prediction to the experimental results is not just a matter of finding the right coefficients, but rather finding the right equation/expression. The equation results (model predictions) are therefore not obvious and need to be tested to verify, if the model actually explains the phenomenon in a satisfactory way.

A new testing experiment, distinct from the observational experiment is in general required when:

- The initial explanation is simple and obviously matches with the observational experiment.
- A quantitative prediction for the outcome of the observational experiment cannot be made based on the model (the equations are too complex, the phenomenon is inherently qualitative, etc.). One such example would be the falling magnet, where there is nothing but the falling time that can be quantified in the original observational experiment. A model to predict the falling time can be produced with sufficient knowledge, but it may be beyond the knowledge of some teams. For these teams, it is better to produce a new experiment such as falling through a series of isolated loops and make a qualitative prediction about the direction of the current in the loops above and those below the magnet. Or suggest a different new experiment such as falling through a tube with a slit in it and making the prediction that the falling time should decrease.

Appendix 5: A simple in-class example – spring oscillator

The YPT process mimics the process of scientific investigations. In this chapter we describe a simple example that can be used with a whole class and illustrates the process and its steps

Decide the problem
Often it is proposed by the teacher, of course.

1	Problem statement:	*A spring oscillator is made from one or more springs attached to a support and a mass attached to the spring(s). Investigate how the oscillation pattern and the period depends on relevant parameters.*
2	Show the experiment, if necessary:	One can show a drawing, a video or an actual experiment for students to see the intended phenomenon.

What we already know: initial model

3	Preliminary (naive) model	Students automatically have an idea about what is going on.
		They should be encouraged to explicitly state this idea.
		This naive idea is the source for the ideas about what would be worth investigating. The possible research questions.

		The spring exerts a returning force on the mass, when the mass is moved from the equilibrium position.
4	Relevant parameters:	From the setup: there is mass, springs, friction, initial displacement. From theory: springs exert force on the mass. The mass moves a certain distance. There is also friction possibly involved. Newton's laws of motion, Hooke's law. So: spring coefficient, mass, friction, initial displacement.

Choose what to investigate further

Each group decides what dependence they will measure. This gives the research questions (RQs)

5	Basic RQs:	How does the period depend on spring stiffness?
		How does the period depend on mass?
		How does the period depend on initial amplitude?
6	Intermediate RQs:	How does the period depend on inclination?
		How does the period depend on friction (below critical case)?
7	Advanced RQs:	How does the period depend on friction (critical and above case)?
		How does the period of oscillations change for large amplitudes of oscillations?
		Is the trajectory perfectly harmonic? What is the anharmonicity of the motion?
		How does the motion change when the attached mass is smaller or comparable to the weight of the spring?
		How will the motion change when the spring deformation will be no longer elastic?
		What if the oscillations are perpendicular to the spring?
		In what circumstances are the oscillation and pendulum modes most coupled?

Some of the above phenomena can be presented by the teacher so that the students know they exist and can choose to investigate them. This preparation phase could take up to 20 minutes.

Build apparatus and perform observational experiments

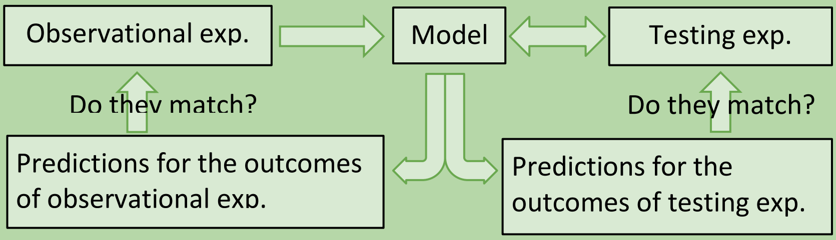
In the next 20 minutes the students build their apparatus and make some preliminary measurements.

8	Build the apparatus	Build the apparatus.
		Choose measurement equipment (stopwatches, rulers, scales)
9	Preliminary (observational) experiments:	Perform a few measurements:
		● Get the feeling about the ranges of the variables.
		● Get a feeling about general dependence.
		● Identify possible experimental problems (stands falling at higher amplitudes or masses, stretch limits of the springs …)

These preliminary experiments serve two purposes: give a feeling for more systematic experiments and give a starting point for building a model or explanation.

Systematic observational/testing experiments

Observational experiments serve to build a model (explanation, equations). Testing experiments serve to test the model. In research the three are often intertwined:



Students should just keep in mind that the ultimate goal is to compare the "experiment with theory", better phrased as "experimental outcomes with model predictions". This means that they should have at least a partial naive model in their head to know what they are going to compare the measurements to. This is why helping them explicitly state their naive model is beneficial. The purpose of the systematic measurements is to refine the model and get data for the eventual comparison with the model.

10	Systematic (testing) experiment	The purpose of the systematic experiments is to see if the model's predictions match the experimental results. Independent of whether the model is built beforehand or afterwards.
11	Collect data	Choose enough values of the independent variable. At the very least three. For mass, spring coefficient and amplitude around 5 should be enough.
		Spread them so that they cover the entire interesting range: most of the available range or the range where changes in the dependent variable (in our case period) are considerable.

		Measure each point multiple times to get a statistic and an error estimation. Three measurements at the very least (but around 6 would be better) for every point.
12	Estimate uncertainties	From the repeated measurements calculate the average and the standard deviation of each point. This gives the error bars.
		A second source of uncertainties are the measurement devices themselves. Scales, measuring tapes, optical gates, thermometers, all have limited resolution and an inherent uncertainty. These are especially important, if the measurements cannot be repeated.
13	Present data	Draw a graph whenever possible.
		Label axes and units.
		Draw error bars.

Building a model
The model is the ultimate goal of science. An explanation of phenomena. There are three levels of model that students can build.

14	Phenomenological model	This model is intended to **describe** the data.
		Examples: $t_0 = C\sqrt{m}$, $t_0 = C\sqrt{1/k}$. The period t_0 is independent of amplitude. Students can be taught to arrive at these models by plotting the data in various forms y vs. x, y^2 vs. x, y vs. x^2, ln(y) vs. x, y vs. ln(x), y vs. 1/x, etc.
		It is just a mathematical description of the observed data (is the relation quadratic, exponential, linear…) without a causal explanation why it is such.
		This is the lowest achievable level. In a simple task, it is expected only from the lowest achievers, but it allows even them to produce a model and succeed in the task. Most students should be able to give a causal explanation.
		In case of very complex problems, it could be acceptable also in YPT competitions, but not scored very high.
15	Qualitative explanation	Propose a qualitative explanation. Why does this happen in words?
		• Find qualitative relations: the stronger the force, the greater the acceleration; the greater the acceleration, the less time to travel a given distance; the greater the mass the lower the acceleration …

16	Quantitative model	Propose a quantitative model:
		• Find quantitative relations between quantities ($F = kx$, $a = F/m$, $x = at^2/2$)
		• Try to relate the dependent variable (time) to the independent variable (mass, spring coefficient, ...). In high school, students are not expected to solve the differential equation, but they should be able to arrive at ${t_0}^2 \propto k/m$.

Comparison

The most important part of a scientific approach is to compare the prediction of the model with the outcomes of the experiment. This is also the most important part of the research part of a YPT activity.

17	Prediction	**Qualitative:** The period should decrease with mass given the same force and increase with spring coefficient given the same mass. Similar predictions can be made for other parameters.
		Quantitative: The quantitative model gives $t_0 = \sqrt{2}\sqrt{m/k}$. But for the comparison it suffices $t_0 = C\sqrt{m/k}$ with C an unknown coefficient. Some students may be able to derive the correct equation $t_0 = 2\pi\sqrt{m/k}$.
18	Comparison	Draw the graph of the prediction on the graph of the measured data.
		Linearize: make the graph linear by drawing t_0^2 on the vertical axis instead of t_0. This is the best way to check the shape of the graph without paying attention to the exact coefficients. And it is enough at this point.
		How well does the predicted line fit with the data? Is it within the error bars or not? In our simple cases the square root dependence should be enough. The correct model for the experiment is $t_0 = 2\pi\sqrt{m/k}$. But not all students can be expected to derive it. An acceptable model for the in-class activity is $t_0 = \sqrt{2}\sqrt{m/k}$, derived assuming constant force.
		Explain any discrepancies. Some students may not be able to fully explain the factor 2π instead of $\sqrt{2}$. But they can consider the fact that the assumption of constant force is not justified. The force and therefore the acceleration diminishes near the equilibrium position. That should increase the travel time. The factor of 2π is greater than $\sqrt{2}$. This is a good enough explanation at this level. Some students may be able to derive the correct equation, but even then there might be deviations from the model that would require explaining.

Report the findings and peer review

The next and arguably the most important phase in the entire YPT activity is the report and the peer review. The peer review includes a peer group whose task is to test the strength of the report.

19	Report	Students state their research questions; their aims.
		They present their experimental setup and data collection process.
		They present their results. Preferably in a graphical form. The dependence of period on mass can easily be presented graphically. Error bars should be included.
		Students present their explanation of the phenomenon: the higher the mass, the lower the acceleration, the higher the period. If the students can find the quantitative model, even better: $t_0 \propto \sqrt{m/k}$.
		Students present the comparison between their model and the measurements.
		Students present a clear answer to their research question.
20	Peer review (discussion)	A different group of students checks how strong the conclusions of the reporting group are.
		They check any part of the report that they feel needs explaining or that they feel is incorrect (usually the model). If data turns out to be unexpected, then the experimental setup should be checked.
		They ask questions to check the reporter's group knowledge of basic relevant physics.

This concludes the YPT process. An evaluation phase can be added where someone (preferably the other teams) evaluate the report and the discussion. More on this will be said later.

Appendix 6: An IYPT example – falling magnets

This appendix presents an example of a problem approached at various IYPT levels.

The problem

1	Problem statement:	*When a strong magnet falls down a non-ferromagnetic metal tube, it will experience a retarding force. Investigate the phenomenon. (2014, problem 16)*

This problem is in line with all the suggestions for problem selection: magnets are relatively easy to acquire and so are metal tubes. There are oscilloscope apps available for computers as long as the voltages are low enough.

Initial observation

2	Perform the experiment as described	It is easy to let a magnet fall through a metal tube. In almost all cases, as long as the diameters are similar, the effect will be very pronounced.

What we already know: initial model

3	Preliminary (naive) model	Students automatically have an idea about what is going on.
		They should be encouraged to explicitly state this idea.
		This naive idea is the source for the ideas about what would be worth investigating. The possible research questions.
		When a magnet is falling the magnetic field at each position in the tube is changing. This results in eddy currents which according to Lenz's rule oppose the change in magnetic field. The field of these currents somehow leads to the retardation of the magnet's fall.
4	Relevant parameters:	Falling: mass of the magnets. Electric currents: resistance of the tube: specific resistance of the material, tube thickness, tube diameter. Interaction between magnetic field and the tube: strength of magnetic field (number of magnets), distance between the magnet and the tube.

Choose what to investigate further

Different teams will decide on different goals of the investigation. However, it is expected that the dependence on identified parameters will be investigated. The more parameters are investigated the better. In general, it is better to investigate one parameter in depth and a few superficially than many superficially and none in depth.

5	Basic RQs:	How does the falling time depend on pipe diameter?
		How does the falling time depend on pipe material?
		How does the falling time depend on the mass of the magnet (at the same magnetic field)

6	Intermediate RQs:	How does the falling time depend on the number of magnets? (The number of magnets changes the mass, the geometry and the strength of the magnetic field.)
		Can we provide evidence that there are currents in the pipe?
7	Advanced RQs:	What is the "shape" of the currents in the pipe?
		What other motion does the magnet perform except falling?
		How does the shape of the magnet affect its motion while falling? (It is very difficult to change the geometry of the magnet while maintaining the strength of the magnetic field constant.)

Build apparatus and perform observational experiments

Depending on the RQs posed, students build their apparatus and perform measurements. This process is often done in parallel with building the model. Students will often be unaware of the underlying steps: build model, perform experiments, compare with model, refine model, perform experiments, compare with model … Usually, only the final model and the final comparison are elaborated for presentation.

8	Build the apparatus	Build the apparatus.
		Choose measurement equipment (stopwatches, rulers, scales, oscilloscopes, optical gates, ...)
9	Preliminary (observational) experiments:	Perform a few measurements:
		• Get the feeling about the ranges of the variables.
		• Get a feeling about general dependence.
		• Identify possible experimental problems (stands falling, measuring difficulties, photogates not triggering, ...)

The following refers mainly to basic and intermediate RQs in this case.

10	Systematic (observational) experiments	The purpose of the systematic **testing** experiments is to see if the model's predictions match the experimental results. However, in this case there will probably be no quantitative model to compare the results to. So these systematic experiments are **not testing, but observational**.
		The purpose of systematic **observational** experiments is to build a model. In this case, the purpose based on the **basic** and **intermediate RQs** will be to build a **phenomenological** model (see Appendix 3): a quantitative **description** of the phenomenon. While the explanation will likely remain qualitative.

11	Collect data	Choose enough values of the independent variable. At the very least three (pipe diameters, pipe material, pipe thickness, …).
		Spread the values so that they cover the entire interesting range, if possible.
		Measure each point multiple times to get a statistic and an error estimation. Three measurements at the very least (but around 6 would be better) for every point.
12	Present data	Draw a graph whenever possible.
		Label axes and units.
		Draw error bars (derived from repeated measurements).

The following refers mainly to the advanced RQs.

13	New testing experiments	In this case, testing experiments to test the qualitative model, must also be qualitative. The model identifies one crucial cause for the retardation of the magnet: the currents in the pipe. Testing experiments must therefore address whether there are indeed currents in the pipe.
		Experiment 1: Cut one or more slits along the length of the pipe. This should prevent eddy currents or at least drastically change their geometry.
		Experiment 2: Replace the pipe with a coil. In this case the currents running in opposite directions above and below the magnet should cancel out except at the very beginning and end. This should almost cancel the retardation. Use multiple coils to amplify the effect at the edges. This should increase the retardation.
		Experiment 3: Let the magnet fall through conducting rings (short coils). There should be an emf pulse registered between the contacts of the rings before and after the passing of the magnet. Use more such rings as replacement for the pipe to arrive at the positional and temporal dependence of the eddy currents.
		Experiment 4: Use rings of different shapes and different geometries to model the expected shapes of eddy currents in previous experiments. Compare the results: do the effects of the variously shaped rings match the effects of the pipe that the rings should model?
14	Collect data	Choose enough values of the independent variable. At the very least three (pipe diameters, pipe material, pipe thickness, …).
		Spread the values so that they cover the entire interesting range, if possible.
		Measure each point multiple times to get a statistic and an error estimation. Three measurements at the very least (but around 6 would be better) for every point.
15	Present data	Draw a graph whenever possible.

		Label axes and units.
		Draw error bars (derived from repeated measurements).

Building a model
The model is the ultimate goal, but depending on the problem, different levels of the model are reasonably expected. For the falling magnet a phenomenological and a qualitative model would be expected. A quantitative model would go far beyond what students are expected to know, but could be achieved nonetheless.

16	Phenomenological model	This model is intended to **describe** the data.
		Examples: Finding a function that with reasonable accuracy describes the dependence of falling time on pipe material, pipe diameter or pipe thickness. This is just a mathematical description without causal explanation or physical justification.
17	Qualitative explanation	Propose a qualitative explanation. Why does this happen in words?
		Example: ● Due to the motion of the magnet, the magnetic field inside the pipe is constantly changing. This induces and emf, which causes electric eddy currents. ● According to Lenz's rule, the magnetic field of these currents will oppose the change. In front of the magnet, the magnetic field is increasing. The eddy currents will, therefore, produce a magnetic field that opposes the direction of the magnet's magnetic field. Behind the magnet, the magnetic field is decreasing. The eddy currents will, therefore, produce a field that will be in the same direction of the magnet's magnetic field. ● The field under the magnet pushes the magnet up and the field behind the magnet pulls the magnet up. This is the observed retarding force.
18	Quantitative model	Add to the qualitative model the quantitative equations.
		Example: ● The magnetic moment can be approximated from the magnetic field as $m = C_1 B V$, where V is the volume of the magnet and C_1 is a constant. ● The induced emf in a loop can be approximated as $emf = C_2 dB/dt$. ● The current due to the emf can be approximated as $dI = C_3\, emf\, w\, dz/(\zeta r)$, where r is the radius of the pipe, w is the thickness of the pipe and ζ is the specific resistivity of the pipe material. ● The magnetic moment of a current loop can be approximated as $m = C_4 I r^2$.

		• The force between two magnetic moments can be approximated as $F = C_5 m_1 m_2/z^4$ where z is the distance between the magnetic moments. • Combining these formulae, one gets $F = C_6 V B\, dz/dt\, w\, r/\zeta \int_0^l grad(B(z'))/z'^4\, dz'$. (1) Here, dz/dt is the magnet's vertical velocity, which can be considered constants when the equilibrium is reached. • From this equation an estimate for the terminal velocity can be obtained: $v_{z0} = C_7 m g \zeta/(V B w r \int_0^l grad(B(z'))/z'^4\, dz')$. • With suitable approximations the integral can maybe be calculated.
		We only considered here the falling time. Due to the unstable equilibrium created by the currents below the magnet, precession of the magnet occurs. This is an advanced phenomenon that can be studied in a similar way as the falling itself. However, we are not considering it in this example.
19	Numerical model	If the quantitative model cannot be solved analytically, a numerical simulation can be used instead. Slicing the pipe into various slices one can obtain a reasonable prediction for the current in each slice and the force due to the current. Then a numerical calculation can show the result either for the terminal velocity or for the falling time.

Comparison

The most important part of a scientific approach is to compare the prediction of the model with the outcomes of the experiment. This is also the most important part of the research part of the IYPT preparation.

20	Predictions	Qualitative: * If we make a slit in the pipe, the falling time will decrease. * If we replace the pipe with a coil, the falling time will be the same as for free fall. * The stronger the magnet (with same mass) the longer the falling time. * The larger the conductivity of the pipe, the longer the falling time. * The thicker the pipe, the longer the falling time. * the larger the mass of the magnet (at same magnetic field), the shorter the falling time.
		Quantitative: The quantitative model gives equation (1) above. Values of many quantities can be predicted using this equation: * the falling time, * the terminal velocity, * the graph of velocity vs, position, * the dependence of all these on all parameters in the equation. The prediction should predict the values that were measured experimentally.

		The easiest to measure experimentally are probably $t_{falling}(m)$, $t_{falling}(w)$, $t_{falling}(r)$ and $t_{falling}(B)$.
21	Comparison	For qualitative prediction, qualitatively compare the prediction with the result. Since the comparison is just qualitative, it is beneficial to have qualitative predictions about different effects.
		For quantitative predictions:
		Draw a graph of predicted value vs. independent variable. For example a graph of $t_{falling}(m)$, $t_{falling}(w)$, $t_{falling}(r)$ or $t_{falling}(B)$.
		Linearize: make the graphs linear by drawing for example 1/w or 1/r on the horizontal axis. This should be linear, if the assumption that terminal velocity is reached very fast is correct.
		How well does the predicted line fit with the data? Is it within the error bars or not?
		Explain any discrepancies. If the linearized graphs are not linear, what could be the causes? Was the assumption that the terminal velocity is reached very soon correct? What kind of changes do we expect in the graph, if the assumption is not correct and are these the changes that we actually observe? Was the shape of the magnetic field correctly approximated?

Report the findings and peer review

This is the most important phase of an IYPT process, and the phase that is done at the tournament.

22	Report	Students state their research questions; their aims.
		They present their experimental setup and data collection process.
		They present their results. Preferably in a graphical form. The dependence of falling time on mass can easily be presented graphically. Error bars should be included.
		Students present their explanation of the phenomenon: the changing magnetic field due to falling magnet induces eddy currents in the pipe, which by Lenz's law act on the falling magnet with their own magnetic field.
		Students present the comparison between their model and the measurements.

		Students present a clear answer to their research question.
23	Peer review (discussion)	A different team of students (the opponent) checks how strong the conclusions of the reporter team are.
		They check any part of the report that they feel needs explaining or that they feel is incorrect (usually the model). If data turns out to be unexpected, then the experimental setup should be checked.
		They ask questions to check the reporter's group knowledge of basic relevant physics.
		The opponent team should not introduce their own solution of the problem. The questions should be based on what the reporter has presented. They are usually based on basic physics involved in the model of the reporter, on the experimental setup, and on minimization of experimental errors. However, the opponent is encouraged to present their own opinion on the discussed topics and here their knowledge of the problem can help.
		Examples of appropriate questions and opinions: * "What makes you think that the terminal velocity will be reached soon?" The opponent may know that it is not reached soon, but cannot say that, because that is not in the data introduced by the reporter. Instead, they can expose the reasoning or lack thereof of the presenter and present their own opinion in the form of: "The free fall model would have the magnet reach the measured velocity at (for example) half the length of the pipe, so I am not convinced that it is reached much sooner". This is based on basic physics and reasoning and no opponent's own data or models. * "There are discrepancies in the comparison between data and theory. How can you explain them?" This is intended to expose the presenter's knowledge of the underlying physics. The opponent can present their own opinion as: "I believe it is a consequence of the terminal velocity not being reached as soon as assumed by the model..." A meaningful debate can arise, if the presenter and opponent disagree on the possible causes. * "If the terminal velocity is not reached soon, how would that change your theoretical prediction?" This question is based on the presented model and is hypothetical, so the opponent can give their own opinion without referring to their own data: "I believe that it would change in the initial part in [such and such] way, and then it would maintain the same slope". * "How would you minimize the measurement errors further?". The opponent can give their own opinion as: "You could make more

		repetitions. You could use optical gates to measure time." … Offering suggestions for improvements is encouraged of the opponent.
		Examples of inappropriate questions and opinions: * "You presented [such and such] model, but we know that, if you derive the equation correctly…" This introduces the opponent's own data or model. * "Your answer was that if we make a slit in the pipe it should not affect the falling time, but we know from our own experiments that …" This again introduces the opponent's own data. On the other hand, it would be appropriate if the opinion was presented as: "Your model says that eddy currents are the cause for the retarding force, so I would imagine that a slice in the pipe would prevent eddy currents and so the falling time would decrease".

This concludes the IYPT process.

Appendix 7: Guiding experimental work

Experimental work can be guided in different ways. Rubrics have proven a good way to guide experimental work without giving specific instructions. The role of a rubric is to lay out a description of what is expected for a particular task and also the common shortcomings. Students should consult them while they work and self-evaluate whether they achieved all that is expected or not. We include in the appendix two such rubrics. Teachers should try them out to see which fits best with themselves and their students. A well researched set of rubrics, designed by the developers of the ISLE approach can be also found at [1]. However, for a class activity the latter might be overwhelming at first. The IYPT scoresheet of 2018 also contains guidance similar to the rubrics and is included in Appendix 13. Naturally, those students who have never used rubrics will require some initial training, but the fact that rubrics are very generic and can be applied to all laboratory problems without changes, makes this training worthwhile. The rubrics can then be used throughout the high school and by age 16 or 17 when students usually candidate for YPT competitions, they will be already very familiar with the use of rubrics.

[1] https://sites.google.com/site/scientificabilities/rubrics

Appendix 8: What is expected? How "new" must the research be?

In the IYPT scoresheet there are rubrics for "own contribution". The question of how innovative the results should be is often asked, especially in cases where a scientific article seems to cover the issue of a given problem in its entirety. Here we present what is expected as “new” in a YPT competition.

- Scientific articles are usually over-formalized. In these cases, the basic physical explanation hides behind the higher mathematical calculations. The invention of a quantitative description and the simplification of mathematics can be considered novel results.
- Repeating experiments with one’s own setup and validating or refining the results is also acceptable.
- For many tasks involving fluid dynamics, the basic understanding of the phenomenon, a few quantitative experiments and an attempt for a phenomenological description of the observations is the maximum which can be reasonably anticipated.
- On the other hand, in tasks where the elementary explanation is straightforward, more focus needs to be put on the originality of the research and on the deepness of the experimental/theoretical study, i.e. advanced questions should be asked and investigated.

Appendix 9: How to motivate students?

Even though the teacher decides to do an in-class activity, it is important for the students to see a purpose and usefulness in that activity to be properly engaged. The main motivation for most students is the possibility for creativity and success, which originates in the open ended problem: the opportunity to decide on the process yourself and to contribute using different skills (e.g. communication, computation, experimentation, visualization, presentation). The reason for exposing all students to project activities is to build a number of competences that transcend a particular subject. Explaining this to students may also add to motivation.

How to find future YPT competition participants?

We have students with different talents. If we provide our students with several types of assignments in basic physics education (e.g. do not limit them to numerical or presentation tasks only), then based on the results of the lessons and students´ activity, the students, eligible for the IYPT can consequently be selected.

Since students are first able to attend IYPT in 10th grade (due to the age limit of 16 years), it is advisable to give students at least 3 different types of tasks already in 9th grade:

- **Traditional calculating tasks*:*** these are primarily used to assess students' general scientific thinking and mathematical skills. It is important not to focus only on the results achieved in the classrooms, because many students produce completely different results due to “time pressure” in the classroom than in a more relaxed home environment.
- **Experimenting / measurements:** With simpler or more complex projects, students with good experimental skills can be noticed. These projects can be assignments performed during

classes, or they can be experiments and measurements at home. The students should make measurement protocols of their experiments. Make sure that projects include both simpler tasks (to ensure success) and more difficult tasks (to select talented students).

- **Presentation (and possibly discussion):** Students should present their project results, as presentation and communication skills are extremely important at the IYPT competition - and, of course, also very useful in life.

Generally speaking, students who perform well in at least two of the assignments mentioned above, and at least average in the third type, can become very successful IYPT participants.

The International Young Physicists' Tournament is extremely complex. Students have to deal with many new tasks (e.g. experiment building, scientific debate) so that they cannot be successful without investing time and energy. Therefore, it is very important to increase the internal motivation of the participants, otherwise they will not take time to deepen the problem, or improve their communication and form a team. **The following opportunities below are interesting for the competition:**

1) **Travel opportunity, multicultural experience.** The competition is usually on a different continent, with more than 30 countries participating. The local organizers do their best to showcase the local attractions. Accordingly, participants can meet exotic destinations and interesting people.

2) **Intense team experience.** Skilful students in study competitions are usually not "top athletes". Therefore, in most cases, they do not feel like team members who are working together to achieve a goal. The IYPT competition offers this unique possibility to participating students.

3) **Interesting physics problems.** Many of the 17 problems arouse students' interest: they want to realize and understand them. Note, that it is not always worth letting them choose according to their interest. Students often tend to choose too difficult problems, which leads to failure (see Section 3.1).

4) **Practicing and deepening English**. For non-native English-speaking teams, it is very important to emphasize that participation provides an outstanding opportunity to practice everyday and specific language.

5) **Universal knowledge elements.** Successful participation in the competition requires a lot of competencies. E.g. presentation, programming, scientific communication, discussion skills. Mastering these is also useful in life even if students don't want to be research physicists.

6) **Get to know the professionals and special tools.** You can often attract students to get acquainted with special (modern, expensive) tools, as well as university (academic) teachers,

researchers, in special cases engineers, chemists, etc.

7) **Representing the country.** It is important to be aware that students represent their own country in this prestigious competition. This makes many students proud, so they take the task more seriously and put more effort into preparation.

8) **It is not only material knowledge that counts!** Many students may be discouraged by the name of the competition, as physicists are expected to have a high level of theoretical knowledge. This may discourage students who are interested, motivated, but do not have the highest physics knowledge. It is worth emphasizing for the students that communication skills count at least as much in this competition as other skills. In addition, developing a problem is not a purely theoretical exercise. The experimental implementation and the high-quality evaluation of the results are just as important.

As we have already mentioned, the competition is very complex, as opposed to traditional problem-solving competitions; there are many other competencies **besides the pure physics knowledge**, so there are many aspects to consider when **selecting students**:

1) **Motivation.** As it was referred to at the beginning of this chapter this competition requires a significant investment of time and energy. This way, only those students will truly succeed who participate with heart and soul.

2) **Team spirit.** Both the tournament and the pre-tournament preparation require teamwork and constant collaboration. Participating can be beneficial for socially disadvantaged students too, it is advisable to keep in mind that it may carry certain risks (can destroy team units).

3) **Creativity.** In this competition, it is important for the students to be able to design novel measurements and apply the theory to their own problem.

4) **Good knowledge of English.** IYPT participants should be able to conduct a fluent scientific discussion (dialogue) in English. Lacking sufficient level of English prevents the students from carrying out such a level of discussion, and therefore they cannot present their real physics knowledge. It is important to note that native English speaking is not required at all, however a solid language foundation is needed.

5) **Good debate skills.** This includes quick reasoning, correct assessment of the situation, self-confidence. During the discussion, students may have to deal with the fact that the other team often comes up with a totally different solution. As an opponent, there is not much time to prepare after the report, to form questions (to identify the most critical points) and then to have a dialogue on the results, in which their own views must be strongly argued for.

6) **Good presentation skills.** Of course, “fights” are based on a scientific presentation. The presentation must be logically structured and planned, and the rhetorical rules must be observed.

Selecting a complete team does not require all students to be equally strong in all areas. There may be 1-2 students who have a high level of theoretical knowledge, others may prefer to experiment or excel in communication. If one of the skills of a student is not as good, then we can expect the greatest improvement in that particular skill, however it is important to strive for an equal balance in every skill-development.

Appendix 10: Opponent template for evaluating the report (SGP)

Problem: ______Reporters: ____________Opponents: ____________Reviewers: ______________

1. Quality of the explanation given by the reporter to the phenomenon.

5 ☺☺☺	4 ☺☺	3 ☺	2	1 ☹
Completely understandable, accurate explanation	Understandable, accurate explanation	Partially understandable explanation, few unanswered questions	Incomplete explanation, questions remained in majority.	No explanation

Comment/Questions: ____

____

2. Quality of the theoretical model used by the reporter to describe the phenomenon.

5 ☺☺☺	4 ☺☺	3 ☺	2	1 ☹
Exact and detailed model	Basically good model	Basically good model with some mistakes	Only described a small part of it	There was no model

Comment/Questions: ____

____

3. Quality of the experimental work of the reporter.

5 ☺☺☺	4 ☺☺	3 ☺	2	1 ☹
A lot of and accurate experiments	Many and accurate experiments	Enough experiments	Few experiments	There wasn't any or very inaccurate

Comment/Questions: ____

____

4. Comparison between theory and experiment

5 ☺☺	4 ☺	3 ☺☹	2 ☹	1 ☹
Theory limits explained, conclusive	Deviations qualitatively analyzed	Mostly good, but not well fitting	Some	No / almost no

Comment/Questions: ____

____

5. Task fulfilment

4 ☺☺	3 ☺	2	1 ☹
Interesting solution	Some aspects above average	Average	Partially fulfilled / misunderstood

Comment/Questions: ____

____

6. Own contribution

4 ☺☺	3 ☺	2	1 ☹
Many new/creative ideas	There were some new/creative ideas	There was one new/creative idea	There weren't own ideas

Comment/Questions: ____

____

7. Science communication

4 ☺☺	3 ☺	2	1 ☹
Overall clear, demonstrative	Some parts well done	Average	Partially clear / unclear

Comment/Questions: ____

____

Appendix 11: Reviewer template for the evaluating the report and the discussion (SGP)

Problem: ______Reporters: _____________Opponent: ______________Reviewers: _____________

1. Quality of the explanation given by the reporter to the phenomenon.

5 ☺☺☺	4 ☺☺	3 ☺	2	1 ☹
Completely understandable, accurate explanation.	Understandable, more or less accurate explanation.	Partially understandable explanation, few unanswered questions.	Incomplete explanation, questions remained in majority.	No explanation.

Comment/Question: ____

2. Quality of the theoretical model used by the reporter to describe the phenomenon.

5 ☺☺☺	4 ☺☺	3 ☺	2	1 ☹
Exact and detailed model.	Basically a good model.	Basically a good model with some mistakes.	Only described a small part of it.	There was no model.

Comment/Question: ____

3. Quality of the experimental work of the reporter.

5 ☺☺☺	4 ☺☺	3 ☺	2	1 ☹
A lot of and accurate experiments.	Many and accurate experiments.	A sufficient number of experiments.	Few experiments.	There wasn't any or very inaccurate.

Comment/Question: ____

4. Opponent's remarks on the strengths and possible missing points of the presentation.

4 ☺☺	3 ☺	2	1 ☹
Strengths and weaknesses were mentioned properly.	Strengths/weaknesses were mentioned unequally.	Only a few strengths/weaknesses were mentioned.	Neither strengths nor weaknesses were mentioned.

Comment/Question: ____

5. Quality and number of the opponent's questions in the discussion.

4 ☺☺	3 ☺	2	1 ☹
Very good questions.	Good questions.	Few or irrelevant questions.	There wasn't any question.

Comment/Question: ____

6. Cooperation of the reporter in the discussion.

4 ☺☺	3 ☺	2	1 ☹
Every question was answered politely.	Most of the questions were answered.	A few questions were answered.	None of the questions were answered, he/she was impolite, often interrupting.

Comment/Question: ____

7. Cooperation of the opponent in the discussion.

4 ☺☺	3 ☺	2	1 ☹
He/she asked politely and efficiently, did not want to present his/her own results.	He/She asked efficiently, but not so politely, some of her/his own results were mentioned.	In an acceptable style he/she was able to create a minimal debate.	He/She could not make a discussion with the reporter. He/She was impolite, often interrupting.

Comment/Question: ____

8. Missed physics and/or questions to ask:

____

____

____

9. I think the win of the discussion goes to the:

Reporter	Opponent	Equal

10. Comments on other aspects:

____

____

____

____

Appendix 12: Rubrics for evaluation of YPT activity (AGR)

Problem:______________ Presenter:______________ Opponent:_______________ Reviewer: _______________

Presenter

0	1	2
Research questions	Are not clearly stated.	Are clearly stated.

0	1	2	3
Choice of experiments.	There are no experiments. The research is purely theoretical.	The experiments do not allow a thorough exploration of the research questions. Maybe the range of possible values is too limited or the equipment does not allow adequate data collection.	The experiments are adequately chosen.

0	1	2	3	4
The physics (models, relations)	The models and relations are not relevant for the problem.	The models are relevant, but there are fundamental errors or uncertainties.	The physical models are mostly correct. There are few minor errors or uncertainties.	The models are correct and detailed.

0	1	2	3	4
Data	No data is collected.	The data analysis has major flaws.	The data analysis contains minor errors. Maybe the analysis of uncertainties is missing.	The data analysis is correct, including the analysis of uncertainties.

0	1	2	3	4
Conclusions	There are no conclusions or they are completely unclear.	The conclusions are not supported by the data. OR there is no clear answer to the research question.	The conclusions and the answer to the research questions contain minor errors.	The conclusions and the answers to the research questions are clear and supported by data.

Opponent

0	1	2	3	4
Questions	There are no questions or they are outside the relevant topics.	Few questions, only clarifications on topics already addressed.	The questions deepen aspects of the presented experiment.	The questions deepen the presented experiment and relevant physics.

0	1	2	3	4
The physics (models, relations)	The models and relations are not relevant for the problem.	The models are relevant, but there are fundamental errors or uncertainties.	The physical models are mostly correct. There are few minor errors or uncertainties.	The models are correct and detailed.

0	1	2	3
Suggested improvements	There are no improvements suggested.	Improvements to the experiments are suggested.	There are suggestions for improvement of the experiments and the physical models. The suggestions are mashed on the presented report and research questions. No new experiments or physical models are introduced.

The numbers in this table are intended as a continuous scale (one could select for example 1.6). However, the table works well also using only integer numbers.

Appendix 13: Official IYPT scoresheet

Look for newer versions at https://www.iypt.org

SCORESHEET

fight (round no.): stage: room: problem no.: Juror´s name & signature:

reporter: opponent: reviewer:

REPORTER

Start from 1 and add/subtract

1 + ☐ + ☐ - ☐ = ☐

REPORT

	phenomenon explanation	theory/model	relevant experiments	comparison between theory and experiment	own contribution	task fulfilment	science communication
0–1	almost no	almost no	almost no	almost no	almost no	misunderstood	unclear, chaotic
1–2	some	some	some	some	review of sources, cited	partly	partly clear
2–3	fair	fair	fair	not well fitting	some own input	average	average
3–4	good	good	well performed, sufficient number	deviations qualitatively analysed	+ some interesting results	some aspects above average	some aspects well done
5	detailed demonstrative	quite detailed, correct	+ results explained errors analysed	+ theory limits explained, conclusive	considerable experimental or theoretical	interesting solution	overall clear, demonstrative
6–7	deep and comprehensible, shows physical insight	detailed, complex, completely testable	+ reproducible, convincing analysis	well fitting, deviations analysed, conclusive	considerable experimental and theoretical	greater extent than expected	+ complex concepts well communicated

DISCUSSION WITH OPPONENT

	relevant arguments/responses	reporter´s conduct at the discussion
0	too few	poor
	some	partly fine
1	many	good
2	+ data/theory supported	some aspects efficient
3	proved deep understanding	overall efficient

ANSWERS TO JURY, OPPONENT, and REVIEWER´S QUESTIONS

0	concise and correct or no questions asked
-1	some incorrect, inconclusive or too long
-2	deeply incorrect or show deep misconceptions

NOTES:

OPPONENT

Start from 1 and add/subtract

1 + ☐ + ☐ + ☐ - ☐ = ☐

QUESTIONS ASKED

0	too few, mostly irrelevant
1	relevant, aimed at resolving unclear points in the report
2	+ short, apt and clear, well prioritized, all time used

NOTES:

OPPOSITION (SPEECH)

	understanding of presentation	relevant topics and prioritisation	own opinions presented	time management
0	almost nothing	irrelevant	too few	poor
1	some main points	too few	some	reasonable
2	main points	some	some correct	fair
3	all relevant points	most	many correct	efficient
4	practically all points	well prioritised	+ improvement suggestions	+ all time used

DISCUSSION WITH REPORTER

	relevant topics and prioritisation	own opinions presented	opponent´s conduct of the discussion
0	irrelevant	too few	poor
1	too few	some	some aspects fine
2	some	some correct	good
3	most	many correct	some aspects efficient
4	well prioritised	+ improvement suggestions	overall efficient

ANSWERS TO JURY and REVIEWER´S QUESTIONS

0	concise and correct or no questions asked
-1	some incorrect, inconclusive or too long
-2	deeply incorrect or show deep misconceptions

REVIEWER

Start from 1 and add/subtract

1 + ☐ + ☐ + ☐ + ☐ ± ☐ - ☐ = ☐

QUESTIONS ASKED

0	too few, mostly irrelevant
	relevant, meant to clarify unclear points
1	+ suitably allotted to Rep & Opp, most time used
2	+ short, apt and clear, well prioritized, time managed efficiently

REVIEW OF REPORT

	evaluation & understanding	pros & cons prioritisation
0	poor/wrong	irrelevant
1	partial	partially relevant
2	good	mostly correct, prioritised
3	detailed, complex	fully adequate, well prioritised

REVIEW OF OPPOSITION

	speech evaluation	pros & cons prioritisation
0	poor/wrong	irrelevant
1	too short/long	partially relevant
2	informative, apt	mostly correct, prioritised
3	condensed & accurate	fully adequate, well prioritised

DISCUSSION ANALYSIS

	discussion evaluation	correct own opinions
0	almost no	irrelevant
	too short/long	some
1	relevant parts	many
2	accurate, conclusive	fully adequate

MISSED POINTS POINTED OUT

-1	irrelevant
0	none
1	relevant, constructive

ANSWERS TO JURY QUESTIONS

0	concise and correct or no questions asked
-1	some incorrect, inconclusive or too long
-2	deeply incorrect or show deep misconceptions

NOTES:

IYPT - February 2020

Please, suitably adjust your grades taking into regard the [1,10] range.