Different approaches to helping students develop conceptual understanding in university physics
A symposium organized by the GTG PERU-Physics education Research at University

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Abstract. In this article we present a summary of initiatives that have been undertaken by a subset of the European Physics Education community to try to help students develop conceptual understanding. The contributions to this article represent a broad spectrum of ideas and research strategies that range from innovative teaching methods, to empirical applied psychology studies. Future physics professionals: scientists, teachers, engineers, analysts etc. are a diverse set of people and therefore the methods used to help them improve their understanding should be wide ranging. However, common themes emerge that we suggest as teaching implications namely: that more attention should be paid to how we develop students’ ability to reason; how building self-confidence can be hugely beneficial to closing knowledge gaps and how the split-attention effect acts to limit students’ working memory.

1. Introduction
One goal of physics education research is to apply the same level of scientific rigour to helping students construct conceptual knowledge that is applied to more traditional experimental domains. However, because physics education research has students at its heart, we cannot treat it as the measurement of completely reductive systems. Students’ learning is impacted by internal factors, external factors, intrinsic motivations, extrinsic motivations etc. Furthermore, researchers are often heavily intertwined in the process of teaching students, and developing instructional materials that arise from physics education investigations. It is then perhaps useful to think of physics education research as a branch of applied physics which borrows from other disciplines such as cognitive psychology, behavioural psychology, ethnography, philosophy, and sociology etc.
In the 1980s, Hestenes [1] argued for the creation of a theory of physics instruction. His argument was relatively simple yet paradoxical: most physics professors take teaching very seriously and yet seem to rely on experience and intuition rather than scientific evidence to support claims of unsatisfactory outcomes of instruction in physics. The paradox arises when you consider that these professors would never rely on experience and intuition in their more traditional physics research. Hestenes argued then that mathematical modelling of the physical world should be the central theme of physics instruction. However, more broadly he argued that substantial improvements in physics instruction could be achieved through a vigorous program of pedagogical research.

In the years between now and then, this program of research has indeed developed, and expanded such that physics education research is now a large and vibrant research community that is as large in scope as, for example, the field of attosecond physics (which is just as old). Ultimately, given the human factors outlined above, a single theory of physics instruction may never be possible. External factors like societal demands of physics instruction, changing cultures of physics students, and developments of other research fields like cognitive psychology means that a theory of physics instruction is inherently a living theory. That does not mean it is void of the level of scientific rigour in other areas of physics. It just highlights the need for the total, global program of research to be vigorous as well as rigorous. This implies a mixed-method approach to some common goals of physics education research: where results from quantitative studies and qualitative studies are combined to inform the outcomes of the research. In this paper, we focus the discussion to the construction of knowledge by students and limit our observations to how that is affected by representations, teaching approaches and problem-solving strategies. We omit “external” factors from this paper e.g. gender, or societal background [2]. Representations refers to the description of portrayal of a physics concept in a particular way, teaching approaches refers to the way in which the presentation and delivery of instructional materials is designed and problem-solving strategy is the plan that students follow to find a solution to a problem or task.

This paper aims to describe some of the innovative teaching approaches, and results thereof across a community of researchers in Europe. All four studies presented here have a theoretical social-constructivist approach to learning [3,4]. This implies that they consider the prior knowledge of the students to be important (studies by Mossy Kelly and Mieke de Cock) and that they use a problem-based approach to activate students' cognitive participation in learning physics (studies by Leoš Dvořák and Michael Thees). In each case, standard research methodology is used according to the specific objective of the study. In this way, two of the studies apply a semi-quantitative analysis for inquiring as to students’ knowledge in two areas of content (light scattering and the use of force and field in electromagnetism) for which there is little research. From a social-constructivism point of view this knowledge is necessary for designing an effective teaching and in this sense the results of those studies provide new knowledge to community of teachers and researchers. In the other two studies, we present examples of how to use the results of the research to improve physics teaching. In those two studies, students work cooperatively to construct their solutions to problems, sometimes with structured on the ‘hands-on’ aspect of practical work, and look at the ways in which their approach is effective at increasing future-teacher/teacher self-confidence (Leoš Dvořák) and in increasing the available working memory in a laboratory task (Michael Thees).

This symposium was organized in line with the aims of the Physics Education Research at University (PERU) Thematic Group within GIREP. PERU aims to bring together professionals with a special interest in research on the teaching and learning of university physics (see https://girep.org/thematic-groups/peru.html ). This kind of approach to a symposium has been effectively used before by the PERU GTG [5,6], and it is along those lines that this symposium exists.
2. Innovative ideas in hands-on and minds-on activities.

2.1. Hands-on, Minds-on practical work in physics teacher training.

Leoš Dvořák presented on the evolution over 20 years of ‘do-it-yourself’ teacher training practical workshops. These workshops were born from feelings in the physics teacher community that there was perhaps quite a gap between the physics that they had learned at university, and the physics they were expected to teach in schools. Thus, a series of activities were developed from “the bottom up” with the goals of linking university physics to physics at schools, theory to the real world, concepts to applications and knowledge to skills. The system has evolved gradually to include:

- Spring camps for future physics teachers: Established in 1997, these are 4-5 days in May, held just outside of Prague for 15-35 participants and are led by young physicists.
- Seminars such as:
  - “Electricity and magnetism Step by Step”
  - “Optics Step by Step”
  - “Teaching physics in a heuristic way”
- “Heureka” workshops and annual conference. Heureka is an informal long-term project aimed at teacher, and future teacher training.

The activities have a heavy focus on informality, and a DIY attitude that build teacher self-confidence, and gives teachers a sense of “ownership” of their activities such that they can bring them to the classroom in an authentic way, having lived the experience as a student themselves.

The do-it-yourself approach in these workshops tends not just to engage the “hands-on” aspect of these activities but the less visible “minds-on” aspect as well. Take, for example, the “Do it yourself optics bench” activity [8] that is often run during the spring camps. This is an exercise where participants must construct an optical bench from basic household materials.

![Do-it-yourself Optical Bench](image)

Here, the ‘hands-on’ aspect is very clear – participants must physically manipulate the materials to produce a working demonstration of an optical phenomenon. They must physically glue bits and pieces together to make a working prototype. Things that need to be stable but move (like lenses and screens) should be able to do that, and things that are fixed in place (like light sources) need to be secure. Furthermore, participants need to give consideration to the design of appropriate light sources etc. However, perhaps less visible but just as important is the ‘minds-on’ aspect of such an activity. For example, if participants are making an approximation to a Galilean telescope, then they need to calculate how long the optical rail needs to be versus if they were testing the focal length of certain lenses. The set up of the workshops means that teachers as future teachers are working together as students and so
will have a chance to discuss the pedagogical aspects of this work too. That is, how will it work in the class room? In what ways will it be appropriate to use as an activity. In the case of the optical bench, it becomes clear through such an activity that while optical demonstrations (e.g. Magnification) are possible by just holding a lens in your hand, but measurements require some sort of apparatus to fix the components.

In another example [9], a simple charge indicator constructed with bi-polar transistors is used to help students see the link between electric charges and electric currents. The device is on a small wooden plate so as to have exact congruity between the circuit diagram and actual construction [9].

![Circuit diagram and photograph of electrostatic detector with a PNP bi-polar transistor.](image)

The behaviour of the device is based on the principle that if positive charge flows into terminal A, then the lightbulb should glow. This can be achieved in many ways such as moving a positively charged plastic rod toward the terminal A, or first moving a negatively charged rod toward A and then moving it away. Indeed, a more humorous example is to connect the terminal A to some part of your body (forehead, for example) and then complete the conducting path to the battery terminal with your hand. Details are given in [9]. Linking the concept of charge, with the flow of that charge (current) is something that students regularly implicitly struggle with, and using this either as a demonstration, or as a do-it-yourself detector acts as an engaging, rigorous way to explore these concepts, as well as lab skills with students. But an activity like this points to a bigger idea: That the expense, complexity, and ‘black box’ nature of commercial devices of this kind really do act as a barrier for students’ intuitive learning of their operation and the concepts behind it. Having examples of simple, cheap, accessible devices of this kind can go a long way to removing these barriers and allowing students to discover core concepts of electricity and magnetism while lowering both the cognitive and economic cost.

The effectiveness of these workshops is measured in both formal and informal ways. Formally, through exit surveys from participants but perhaps more powerful is the informal feedback. In these spring camps and heureka workshops – participants are not placed in luxurious conditions (i.e. they sleep in the classroom). Yet still, participants keep coming back, and keep participating. The feedback from teachers is positive – teachers enjoy the active working and especially the building of tools by themselves. All seminars for teachers are evaluated by their participants. They value two factors: how the content was interesting for them personally and how it was useful for their teaching, both on Lickert scale from -2 (worst) to +2 (best). (The questionnaires are detailed; participants value both the whole seminar and particular activities. This is used for formative assessment of the seminars.) Typically, the average answers are above +1.5; see [10] for seminars concerning semiconductors. Seminars for future physics teachers are valued by students in surveys organized each term by Faculty of Mathematics and Physics; results are consistent with the above-mentioned evaluation by teachers; see also students’ feedback in [11].
2.2. AR-Smartglasses as Assistive Tools for STEM Laboratory Courses
Michael Thees presented an empirical study on the use of augmented reality “smartglasses” in introductory physics labs. The aim was to use specially designed augmented reality devices as a way of managing cognitive load. According to cognitive load theory [12], learning occurs when knowledge structures and processed conceptual information is passed from the working memory to the long-term memory. In a physics teaching lab setting, the content and activities that students are presented with add to the working memory which is important for decision making and behaviour, but has limited resources. Cognitive Load Theory splits the cognitive resources used by the working memory as having three functions: *intrinsic load* is related to the inherent difficulty of the topic at hand; *extraneous load* is related to how the activities are presented to the student, and *germane load* is related to the resources dedicated to creating the permanent storage of knowledge. The central thesis of cognitive load theory states that knowledge building can be improved if attention is paid to reducing the extraneous cognitive load [13].

Consider, as an example, the introductory lab activity of finding the steady-state temperature distribution of a heated metal rod. In a traditional workflow for this lab exercise, a student would set up a metal rod with a heat sink on one end, and some form of heating element at the other. The student would then use some external apparatus (such as a thermal camera) to monitor the temperature at different spatial points along the rod. Photographs would be taken every so often, and then later plot the spatial temperature distribution at different times and evaluate the data to decide when the rod has reached the steady state. The data would then be fit to the one-dimensional diffusion equation to find the thermal conductivity constant, if the length and cross section are known. This experiment is repeated for different materials and with a thermal isolation around the rod. It is easy to see, when applying the theory of cognitive load, how such an experimental process can affect the working memory of the student: Most primarily, this is done through the overloading of the extraneous cognitive load from the so-called *split-attention effect*. This is created by information sources being either temporally or spatially separated from the learner’s attention and the physical phenomenon. For example, the student must manipulate and monitor several devices at once in the traditional experiment, keep the information in mind and then some time later integrate all the information to construct knowledge. There are also cognitive resources spent on tasks which are not directly related to producing the knowledge schemata such as deciding when to take photographs with the thermal camera, and how many to take and many other troubleshooting aspects of the activity.

![](image)

*Figure 3* Schematic showing 'traditional workflow' for the heat conduction experiment (red arrows) and 'adapted workflow' using the AR-smartglasses (blue arrows).
A proposed new workflow places augmented reality technology in between the student and the apparatus, in place of external monitoring equipment in the form of AR-smartglasses [Fig. 3, 14]. These glasses give spatial and temporal contiguity to the exercise by reducing cognitive activities that are not directly related to the learning process. As shown in Fig. 4, AR allows for the experimental raw data to be viewed in many different representations such as false colour diagram or the exact temperature graph, representing qualitatively and quantitatively the thermal state of the experiment. The information is presented in real time and the virtual elements are spatially connected to the corresponding components of the real equipment [Fig. 3, 15]. Thus, in theory, this contiguity should decrease the extraneous cognitive load by enabling students to reflect about the experimental process while performing the measurement and to think properly about when to export the data. Furthermore, students remain hands-free to manipulate the experiment without interrupting the traditional workflow.

![Figure 4](image-url) Photographs of the 'traditional' experimental setup (left) and the 'adapted' setup with AR-smartglasses (right).

A controlled test was performed which contained a control group (CG) who used traditional hand-held apparatus to perform a heat conduction experiment, and a test group (TG) which used the AR-smartglasses. A 15-minute pre-test was used to determine students’ conceptual knowledge of the topics using a standard validated concept test [16] and a 15-minute post-test that measured conceptual knowledge and subjective cognitive load [16, 17].

![Figure 5](image-url) Preliminary results of the controlled study showing a decrease in extraneous cognitive load, $n_{CG} = 16, n_{TG} = 19$

The preliminary results show that for the test group there was a significant gain in conceptual knowledge after the experiment with a small effect size, $F = 5.61, p = .02, d = 0.43$. The extraneous cognitive load was significantly reduced with a medium effect size, using “usability” as a covariate: $F = 6.02, p = .02, d = 0.56$. Hence, this approach can be seen as a first step to create a more effective and efficient workflow for university experiments by using AR and smartglasses.
3. Semi-quantitative analysis of students' reasoning.

3.1. Students' use of Dual processing theory when evaluating experimental data.

Mossy Kelly presented on the development of a new laboratory curriculum at the University of Hull Physics Department which aimed to create an environment where students could construct knowledge [18], rather than a place where students were instructed in the right way to confirm things. The talk focused on a middle-division lab sequence which aimed to operationalise the learning goals set out by the AAPT [19]. These learning goals were operationalized in a closed inquiry format, where students were given a research question, and then were free to choose their own way of solving the problem, subject to the resource constraints of the lab. The students were given, in total, 12 hours of teaching contact time to: Design an experiment to answer the research question, troubleshoot the experiment, collect and analyse the data, and write a short report (whose template was based on the technical note style of the Measurement Science and Technology journal) on their activities. Students were presented with resources in the form of bespoke YouTube videos and specially selected research papers to help guide them. During the lab time, instructors were available for guidance but mainly taught through questioning rather than direct instruction. After writing their lab report, the students received an audio-visual podcast where an instructor (Mossy Kelly) opened up their report and gave feedback in three areas: the quality of the data / experiment; the style and structure of the report and the use of argumentation. The students were only given the feedback on the report, not a grade. Furthermore, the feedback was consciously designed to give a professional opinion on the science behind the work and tried to avoid resorting to “this is bad” / “this is good” type language. The aim was to present feedback to students as a dialogue rather than one-way objective judgement. Over 12 weeks, the students were given 4 research questions to investigate. At the end of the process, they chose one of their short reports to turn into a longer-form report much more closely related to a typical research journal article. The students also had to submit a cover letter explaining how they used the feedback from their original short report, to develop the final report.

Ideally, through this sequence, students would not only get better at the technical aspects of laboratory research, but would develop over time to think and act like scientists. In the framework of the AAPT learning goals, this means they would engage in the process of constructing knowledge in an expert like way. An outstanding question is – how do we correctly measure if that is happening? More specifically, how do we measure that it is happening in a way that does not undermine the overall goal of the curriculum re-design. That is to say, the goal is to create an environment where students feel comfortable exploring and constructing knowledge in exactly the way it has been done historically. This inevitably means that students need time and space to get things wrong, to go back over things, to try to resolve inconsistencies either in their model or their experimental design. In terms of the role of the instructors, we take an ethnographical approach: We wanted the students to see us as helpful advisors rather than assessors and, specifically, for students to see the lab space as a community of student physicists. Therefore, the approach we decided upon was to prepare open ended pencil-and-paper type questions that students would answer in the preparatory phase of each research investigation. The questions were designed as guidance for the students while they prepared their experimental plan, but were also designed to focus on key aspects of expert-like scientific behaviour. Here, we present one such question which was used to probe whether students spontaneously used mental models when thinking about abstractions of experimental apparatuses, or whether they followed their ‘gut instinct’.

Students were asked to compare the total amount of light scattered in the first half of a glass tube containing a suspension of polystyrene particles, to the total amount of light scattered in the second half and choose whether the total scattered light in $x_1$ was greater than in $x_2$. 
Students were told that the particle distribution was uniform, and were told that the particle radius was much less than the wavelength of the light. Students were then asked to explain their answer. In a follow up question, students were asked to predict how the total amount of light in x2 would change if the number of particles was increased – whether the total light scattered in x2 would increase, decrease, or stay the same. Again, students were asked to explain their answer.

The choice of context for this question was based on an analysis of topics that had been covered in physics labs historically. Historically, the topics covered in labs were determined by a combination of equipment and budgetary resources available and academic staff’s expertise and interests. Now that the labs were being re-designed into a set of research questions that aimed to focus on (amongst other things) the modelling aspect of experimentation – the choice of topics was important. In this case, light scattering was chosen as an activity because it contained different models that could reasonably be compared by students, without complex data collection / analysis and crucially allowed for the testing of predictions. Essentially, this question aimed to probe students spontaneous reasoning strategy when asked to predict the ramification of a change to a light scattering model. Students answers were then analysed and categorised based on their reasoning rather than which answer they chose. Four categories were found in the data. For the question where students were asked to predict what happens when more particles are added, 53% of students said that the amount of light scattered would increase. The overwhelming argument was based on how the probability of scattering will be affected eg. “If there are more particles, there is a greater chance that light can be scattered, therefore the signal will increase”. 21% of students said that the signal would decrease. Here, answers tended to be based purely on the number of photons available “If the number of particles is increased, then there will be fewer photons available to scatter in x2”.

It is clear from the majority of student answers, whether they choose a probability, or a photon number explanation – that there is little evidence of scientific modelling in their answers. Students by and large seem to simply state what they think is a fact. This is discouraging because there is not factual answer to the question. Given how it is phrased, an answer can only be arrived at if basic aspects of modelling are included such as the assumption (based on the pictorial representation) that a significant amount of flight exits the tube could imply that the scattering does not deplete the main beam, and in fact increasing the number of particles may increase the amount of scattering in x2. Conversely, one could look at the pictorial representation and surmise that the light level exiting the tube is in fact quite low. And so perhaps increasing the number of particles would increase the scattering in x1, leaving fewer photons to scatter in x2 and so the amount of light would decrease. The point is – this kind of reasoning is largely absent from the students answers. It points to a number of possible teaching implications:

1. Linked to extrinsic cognitive load, or the cueing of resources – it is clear that students in this cohort are not spontaneously using lines of reasoning in their answers. It may be the case that this reasoning is taking place, albeit internally and all we are seeing from the answer is the final integrated and filtered product. Therefore, perhaps a re-phrasing is order to something like: “Describe in detail your reasoning behind why you chose the answer you did”.
2. It could also be the case, that for many reasons students simply are not analysing the situation. Recent evidence suggests that many perceived conceptual difficulties in students’ answering of problems could be explained by Dual-Process theory [20]: The idea that students heuristically reach for the first available mental model of a situation and if they can convince themselves to be confident of the result, they will expend no more cognitive resources on the issue (confirmation bias). A sign of an expert learner, is one who will as a matter of course always engage an analytic cognitive process to try to rule out the first available mental model using scientific reasoning. It is clear from the student answers, that there is no evidence of students engaging with that process from their written answers.

3.2. Students’ use of field and force ideas in the context of E&M
Mieke De Cock presented on the results to a questionnaire which probed students’ ideas of force and field in the context of electricity and magnetism. Electric force and electric field are two related but distinct concepts. Often, in introductory physics textbooks, students learn as fact that “charges exert forces on each other”. This fact comes with additional caveats such as the fact that the force is inversely proportional to the square of the distance between the charges, points along the line joining the two charges and that charges of the same sign repel whereas charges of opposite sign repel. The electric field can then be defined as the “force per unit charge” at various points in space. This is known as the force/Newtonian model. Later on, in textbooks, the field theory is introduced. In this - more abstract - picture, charge appears as a property that some objects have. Objects with this property will create a disturbance in the space around them known as the electric field. Other objects that have charge and that are placed in regions of space where the electric field is present, will then feel the force. The same ideas are true for the magnetic force and magnetic field. In fact, in the early days of research on the interaction of charged bodies, the experimental findings of Coulomb seemed to confirm that electrostatic interactions were analogous to gravitational interactions. However, the observation of non.central magnetic forces led physicists of the time to give the space around objects a prominent role, and hence developed the field theory. The later observation that these interactions travel at a finite speed rather than appear instantaneously led the scientific community to adopt the field model as being a more powerful description of the classical world. This view is known as the field/Maxwellian model.

It is well known, that students will often adopt the force/Newtonian view of the world when answering problems in electro/magneto-statics [21]. Furthermore, when students do invoke the concept of the field, it is done still from a force-based perspective, diminishing the role of the field as being a calculation tool that is derived from the force. While this strategy may allow students to solve routine calculation-based problems, their lack of a coherent understanding and application of the field theory leads to conceptual misunderstandings when dealing with unfamiliar situations in E&M. For example, the view of the field as a Coulombic calculational tool can, in some cases, lead to the profound misconception that field lines are entities that impose a path on a charge – which is of course an absurd misconception for the case of a moving test charge placed near a current carrying wire.

In this talk, a brief review of the history and epistemology of the field theory was described in the form of 5 key epistemological characteristics that relate to the field theory. These are key ideas that students need to grasp in order to understand the Maxwellian field theory. Coulombian electric fields are produced by charges, magnetic fields are produced by moving charges (K1); The concepts of force and field are related but different (K2); There is no ‘self-force’ (K3); The principle of superposition applies (K4); Changes in the electric and magnetic field propagate at the speed of light (K5). This led to the design of a questionnaire to answer the following research questions:

- “What kind of reasoning strategies do students adopt when solving problems on E/B fields?”
- “Is there a difference between student answers on problems in an electric versus magnetic context in terms of strategies?”

Two open ended questions were designed and administered at 3 European Universities (KU Leuven, Dublin City University, and University of the Basque Country). One question focussed on electrostatics and the other on magnetostatics. The questions were open ended, and not mathematically complex.
Figure 7 Electrostatic (top) and Magnetostatic (bottom) questions to probe students' reasoning.

A long isolating cylinder is uniformly charged, i.e. the charge density inside the cylinder is constant. A cross-section of the cylinder is shown.

a. Is the value of the electric field at point \( P \), \( E_P \), zero or non-zero?
b. Is the value of the electric field at point \( S \), \( E_S \), zero or non-zero?

Justify your answers.

A wire of radius \( R \) carries a current that is uniformly distributed over the cross-sectional area.

a. Is the value of the magnetic field at point \( P \), \( B_P \), zero or non-zero?
b. Is the value of the magnetic field at point \( Q \), \( B_Q \), zero or non-zero?

Justify your answers.

A categorisation scheme was developed bottom up from the data by having individual researchers propose a categorisation scheme from their data, and then finalizing the scheme in a face to face meeting. The categorization of the answers was not based on whether it was correct/incorrect but rather on which argument or theory students used when answering. Students who answered primarily using either Gauss’ Law or Ampere’s Law were categorised as having a Maxwellian view, whereas students who reasoned based on superposition were categorised as having a Newtonian view.

|                | KU L (N=100) | DCU (N=60) | UPV (N=96) |
|----------------|--------------|------------|------------|
| Gauss’ law     | 19           | 2          | 28,6       |
| Superposition  | 6            | 18         | 5,7        |
| General statement | 56      | 62         | 58,6       |
| Incoherent / No answer | 19      | 18         | 7,5        |

|                | KU L (N=100) | DCU (N=54) | UPV (N=96) |
|----------------|--------------|------------|------------|
| Ampère’s law   | 15           | 15         | 36,3       |
| Superposition  | 4            | 15         | 3,2        |
| General statement | 53      | 52         | 48,3       |
| Incoherent / no answer | 28      | 19         | 13         |

Figure 8 Categorised student responses to questionnaire.
The study found that very few students adopted a Maxwellian view when reasoning out the solution to the question, and even those who did seemed to not have a coherent idea of the field theory. Perhaps more alarming, is the large number of students who were categorised as giving a ‘General Statement’. This category was reserved for students who rightly or wrongly, simply quoted a learned rule, or equation to try to answer the question. Examples include statements referring to material or geometrical properties (e.g. the E-field inside an insulator is always zero; inside a wire, the B-field is zero). This category is heavily populated in all three European Universities.

4. Discussion and final remarks.
At the end of the symposium, the discussion was led by Kristina Zuza who pointed out that while each talk was different in its scope and approach, a common thread is as follows – that as teachers we try to help students build models that work to explain physical situations, and solve problems [22]. The way in which we try to help students build those models might focus on trying different teaching strategies, or trying to understand how students approach problems, or trying to help students become fluent in different representations but the focus is always on helping students develop models to explain physical phenomena and, from that, construct knowledge.

Each talk has its own individual conclusions, or teaching implications. However, by viewing each talk as a different piece of the overall pie, there are broader conclusions / implications. For example, in both the talks of Mieke and Mossy, it is clear that students really struggle when asked to “Explain…” something. In the talk of Mossy, this is interpreted along a heuristic / analytical framework, whereas in the case of the talk of Mieke, it is interpreted in a phenomenographical sense. Nonetheless, the same observation is in both talks – that students have real difficulty in understanding what is expected of them when asked to explain. In fact, it came up during the discussion at the end of the symposium, that if students do indeed have these difficulties, then perhaps it is somehow producing an internal barrier to students’ answering of exam questions. This is not unrelated to the concept of extrinsic cognitive load, as in the talk of Michael Thees. In the talk of Leoš Dvořák, it was noted that the hands-on, minds-on workshops were informally very effective at building teachers, or soon-to-be teachers’ self-confidence. In particular, the minds on aspect was appreciated by participants and so the workshops seem very effective at achieving their goals. This result seems to complement the results of Michael Thees’ talk which showed, in a controlled study, that embedding live data (hands-on) together with removing split attention effect (minds-on) lowered the extrinsic cognitive load.

![Figure 9](image_url)

**Figure 9** Figure representing the different aspects that focus on building physical models.
All three of Mossy, Mieke, and Leoš’ talks concentrated on the benefit of developing things “from the bottom up”. Whether that is designing laboratory activities, categorisations, or workshops activities – the bottom up approach was adopted. In addition, Mieke’s talk showed that the difficulties that students have with holding a coherent theory seems to exist across different European institutions. This is interesting because it suggests that developing and validating research studies at individual institutions is, in some cases, perhaps a valid way to research teaching implications that may be applicable to different universities. Not every university can research everything, and cross-institutional studies are sometimes difficult in particular at upper-level and in laboratory settings because university curricula at that level tend to be more sensitive to historical / current departmental research interests than the introductory level.

Overall it is interesting to see that there is a wide variety of techniques, approaches, and strategies to helping students develop physical models using the social-constructivist framework. It is even more interesting to see that even though these strategies were formed locally, based on local needs – that there are similar findings and complementary discoveries from the studies.

Additional remark
Of course, PERU can only succeed with the help of people like you contributing and attending the symposium. If you are interested, please send me a note with your contact information and your area of expertise. Let me know if you have suggestions for a themed issue. We always welcome your suggestions, comments, and constructive criticism. You can email me at Jenaro.guisasola@ehu.es and see the web site. https://girep.org/thematic-groups/peru.html.

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