Annotated Bibliography : How students learn in physics – the difference between experts and novices

Brault Foisy, Potvin, Riopel and Masson (2015)

Brault Foisy, L.-M., Potvin, P., Riopel, M., & Masson, S. (2015). Is inhibition involved in overcoming a common physics misconception in mechanics? *Trends in Neuroscience and Education*, *4*(1–2), 26–36. https://doi.org/10.1016/j.tine.2015.03.001

Key-concept: *Experts inhibit misconceptions.*
Citation: *(Brault Foisy, Potvin, Riopel, & Masson, 2015)*

Using fMRI (functional magnetic resonance imaging), Brault Foisy, Potvin, Riopel and Masson look at the brain areas that are activated in novices and experts while solving scientific tasks. The results show that areas connected to inhibition have more activity in experts than in novices. According to Brault Foisy et al., this aspect of inhibition was not taken into consideration by many studies on conceptual change that focused on how misconceptions are transformed or replaced when becoming an expert. It looks like these misconceptions, even in experts, are not replaced or transformed, but rather coexist with scientific knowledge.

These results are important as they imply that trying to focus on how to replace or transform misconceptions will not necessarily help students to become experts. Instead, as the authors argue, physics education should put more emphasis on learning to inhibit the misconceptions and identify the context when such inhibition is particularly important.

Buteler and Coleoni (2014)

Buteler, L. M., & Coleoni, E. A. (2014). Exploring the Relation Between Intuitive Physics Knowledge and Equations During Problem Solving. *Electronic Journal of Science Education*, *18*(2). Retrieved from http://ejse.southwestern.edu/article/view/11993/0

Key-concept: *Experts refine preconceptions.*
Citation: *(Buteler & Coleoni, 2014)*

Buteler and Coleoni present a case study on the link between preconceptions (or "physical misconceptions") with formal mathematical equations and the ability of the students to understand the results. Two groups of students (2 students in the first, 3 students in the second) were guided by an interviewer to the problem solving-process and asked to think aloud.

The problem presented to the students was the same for each group: A ball is partially submerged in the water. Oil is then added until the ball is completely covered. Will the ball sink, rise or stay at the same position? Both groups started with the same preconception: That of a force being the cause of a movement. Based on this, initially, both speculated that the ball will sink due to the added pressure of the oil on the top of the ball. While the first group was then instructed to ignore the force-as-a-mover concept and simply write out the buoyancy equations and solve it, the second group was guided into using the force-as-a-mover concept to develop the buoyancy equations themselves. With help, both groups arrived at the correct conclusion: The ball will rise. However, the first group was utterly puzzled and in disbelief as this result was in stark contrast to their initial thoughts. In comparison, the second group had a true eureka moment, as their initial thoughts have been used to elaborate a solution that is absolutely logical to them.

Buteler and Coleoni show that when fighting or ignoring the preconceptions, the students might solve a problem but do not understand it as they do not think that the result makes sense. Instead, when using those preconceptions in the solution process, the students refine them and arrive at a much deeper understanding. It is this "refined physical intuition" that Butteler and Coleoni claim to be at the source of expert knowledge.

The authors themselves acknowledge that the sample size in their study is too small to be able to generalize. However, they back up their idea of refining the preconceptions instead of overcoming them with the work by Sherin (Sherin, 2006) on the role of intuitive knowledge in physics problem solving. It has to be noted that, as reported by Buteler and Coleoni, Sherin studied only two students. Treating the initial conceptions of students as a starting point for the development of expert knowledge is one of the many ways how different authors treat those conceptions. The paper is special as it considers the preconceptions to be useful to increase student understanding.

Chi, Feltovich and Glaser (1981)

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, *5*(2), 121–152.

Key-concept: Expert representation is richer and based on physics principles, Novices rely on surface information
Citation: (M. T. Chi, Feltovich, & Glaser, 1981)

In this 1983 paper, Chi, Feltovich and Glaser report on the result of four studies on the difference between novice- and expert-approaches to physics problems. In the first two studies, the participants were asked sort the problems into categories of their choice. In the last two studies, Chi et al. investigated further how the participants choose a category, their connected knowledge and how they would start solving the problems.
While experts took significantly longer for the sorting task, their categories were based on the underlying physics principles. The novices were faster but based their decision on the surface structure of the problem alone. (Example: “Newtons 2^{nd}“ law for experts vs. “inclined plane” for the novices). By not examining the underlying principles, the novices came up with more categories as the experts. The results also revealed that experts, as well as novices, started the process looking for the same keywords, but the experts then elaborated further before choosing a category. This hints that the experts did not have a different, but a larger knowledge base. When asked to describe the basic approach to solving each problem, the novices gave either general (mostly useless) statements or jumped directly into a detailed equation. The experts always looked at the principles they had used in the categorisation first.
The authors link their results to the consensus [Dekleer (1977), Novak (1977), Reif (1979), Simon (1972, 1976, 1978) and others] of the time: Expert representation is superior because of the larger quantity of qualitative knowledge, leading to the ability to establish links between a problem and the representation faster.

While the paper of Chi et al. now dates back more than 30 years, it is still heavily cited as many current work in the domain is based on this initial characterisation of experts and novices in physics. It thus belongs in any literature review on the topic of how students learn in physics.

Erylmaz Toksoy and Akdeniz (2015)

Eryılmaz Toksoy, S., & Akdeniz, A. R. (2015). Determining Student Difficulties in Solving Problems Related to Force and Motion Units via Hint Cards. *TED EĞİTİM VE BİLİM*, *40*(180). https://doi.org/10.15390/EB.2015.3817

Key-concepts: *Superficial problem solving, Self-Confidence*
Citation: *(Eryılmaz Toksoy & Akdeniz, 2015)*

Toksoy and Akdeniz (2015) analyzed student difficulties when solving grade 10 force and motion problems with the help of hint cards. They report that many students, instead of making a plan, showed superficial problem solving, trying to substitute the data into the formulas given on the hint cards. The main difficulty, as perceived by the students, was to identify the variables in the formulas. The students did not realize that their main issue was not understanding the problem itself. As the students showed little awareness about their own problem-solving process, the hints did only help to a certain extent. Instead of trying to understand the problem, they are trying to relate the problem to a similar one they have already solved.
According to the authors, in order to successfully solve the problems, the students need to understand the problem and make a clear problem-solving plan before starting to substitute numbers into formulas. Toksoy and Akdeniz, therefore, suggest that teachers ask the students to provide a plan before starting to solve a problem. Another issue identified in the paper is that the student's problem solving-skills are affected by their beliefs. If they think they can't do it, they will not be able to. The authors, therefore, think that it is crucial to start with simple problems in class to show the students that they are capable of solving them.

Like Chi, Feltovich and Glaser (M. T. H. Chi, Glaser, & Rees, 1981), this recent study shows ones again a main difference between novices and experts in physics: novices use a basic surface approach while experts rely on the underlying concepts. It illustrates that the research on the challenges students face in solving physics problems that started more than 30 years ago is still continued. While Chi et al. looked at the basic approach students choose and how they categorize the problems, Toksoy and Akdeniz actually had the students solve the problems completely, and in doing so, added further insight on the thematic.

Lasry, Guillemette and Mazur (2014)

Lasry, N., Guillemette, J., & Mazur, E. (2014). Two steps forward, one step back. *Nature Physics*, *10*(6), 402–403.

Key-concept: Force concept inventory, instability of pre-conceptions.
Citation: (Lasry, Guillemette, & Mazur, 2014)

Lasry, Guillemette and Mazur present the results of analyzing the force concept inventory tests of 13'000 university and college students across the US and Canada.
The force inventory test (FCI) is a widely used tool in physics education. It is usually given before and after a mechanics course to measure the conceptual change. The test consists of multiple-choice questions that do not require any calculation. The incorrect answer options have been elaborated from student interviews in order to match the thinking of the students and not the one of the instructors. Questions answered incorrectly on the first test, but correct on the second test, are considered a "gain", questions answered first correctly but then incorrectly a "loss".
As expected, there is a gain (46%). But as a surprise to the authors, there was also a loss of 30%. Based on these data, the conclusion is made that the pre-concepts are not stable. More importantly, given the high loss rate (significantly more than the expected correct guess rate of 14%), constructing expert knowledge seems to be a highly nonlinear, fragile process. Lasry et al. also identify that gains are much higher for students that already performed well on the first test. The bigger the initial concept network, the easier it seems to integrate new concepts.

This short paper will be used in the literature review because of its clear description of the force concept inventory test (FCI). The FCI is regularly given to students across North America and plays a key role in the research on student understanding and effectiveness of teaching strategies. Further on, Lasry et al. show than the initial concepts of novice students are unstable and that physics education therefore, while increasing the knowledge of students with a strong background, has a destabilizing effect on others. This is an interesting new aspect of the role of student preconceptions that adds to the research on how these pre-concepts influence the development of expertise.

Lin and Singh (2015)

Lin, S.-Y., & Singh, C. (2015). Effect of scaffolding on helping introductory physics students solve quantitative problems involving strong alternative conceptions. *Physical Review Special Topics - Physics Education Research*, *11*(2). https://doi.org/10.1103/PhysRevSTPER.11.020105

Key-concept: *Alternative Conceptions, Use of analogies to reorganize knowledge*
Citation: (Lin & Singh, 2015)

Lin and Singh explore the effect of using analogies between similar problems to resolve the conflict between well-established physics concepts and alternative student concepts.
The problem used in the study is the classical “object on inclined plane” problem where students are asked to find the static friction. According to Lin and Singh, previous studies have shown that, due to the interference with the alternative conception of friction being equal to the coefficient of friction times the normal force, only about 20% of the students are able to answer this question after receiving a traditional instruction. Interestingly, a similar problem, with tension holding the object still, can be solved by more than 77% of the students. This suggests that the students are able to execute the procedures of Newton’s Laws to solve such a problem and that the interference with the alternative conception must be the cause of the failure.
The idea of the authors is to use the analogy of the tension problem to help students reorganize their knowledge structure and refine their alternative concepts. Three different approaches were used and compared with a control group. While the control group was directly given the friction problem (after normal instruction), the other groups were exposed to the related tension problem first. Group one was provided the solution for the tension problem, asked to reproduce the solution and then solve the friction problem. Group two was first asked to solve the friction problem, then given the solution to the tension problem and then asked to redo the friction problem by comparing with the tension problem. The last group was simply provided the solution to the tension problem and asked to solve the friction problem by comparing it to the given solution.
All three groups performed better than the control group. However, the second group, which had to try to solve the friction problem first, performed best. Interestingly, the third approach (directly using the tension solution to solve the friction problem) worked for the calculus-based courses but not for the algebra-based courses. It seems that the prior knowledge of the calculus-based group situated them better for this approach.

The study agrees with Lasry, Guillemette and Mazur (Lasry et al., 2014) that alternative student conceptions are robust and difficult to overcome. Instead of just trying to replace the conception, Lin and Singh try to refine it through an analogy process. However, while working with the initial student conception, the authors do not go as far as Buteler and Coleoni (Buteler & Coleoni, 2014) to say that the students alternative conception was actually useful. It will be used in the literature review to illustrate the many nuances in researcher-opinions on how alternative student conceptions transform into expert knowledge.

Priest and Lindsay (1992)

Priest, A. G. & Lindsay, S. O. (1992). New Light on novice-expert differences in physics problem solving. *British Journal of Psychology,* 83, 389–405.

Key-concept: *Order of equation generation, artificial intelligence, simulation of expert/novice behaviour*
Citation: *(A. G. Priest & Lindsay, 1992)*

Priest and Lindsay report on various computer models that have been created to test the differences found for experts and novices solving physics problems. All systems either use a forward inference or a hybrid of forward and backward inference. In backward inference, the solver starts with an equation that includes the variable that needs to be found and generates additional equations to find the other unknowns in previous equations if needed. In forward inference, the solver starts with the equations that contain the known values and generates additional equations until the variable it is looking for is found. MECHO by Bundy, Byrd and Palmer (Bundy, Byrd, Mellish, & Palmer, 1979) and PDP-10 by Jansweijer, Eishout and Wielinga (Jansweijer, Elshout, & Wielinga, 1986) are using only backward inference. ABLE by Larkin, McDermott, Simon and Simon (Larkin, McDermott, Simon, & Simon, 1979, 1980), EUREKA by Elio and Scharf (Elio & Scharf, 1990) as well as the systems by Priest (A. Priest, 1986b, 1986a) and Lamberts (Lamberts, 1990) start as a backward solver, but use various methods of stacking and problem memorization to recall the equations for similar problems and, with experience, become forward problem solvers.

All this research uses the hypothesis that the difference between experts and novices is that experts solve a problem with forward inference, while novices rely on backward inference. Priest and Lindsay critique that this hypothesis relies greatly on the findings by the study on physics problem categorization by Chi et al. (M. T. H. Chi et al., 1981) and physics problem solving by Larkin et al. (Larkin et al., 1979, 1980). The goal of this study by Priest and Lindsay is to repeat those findings with a study that includes larger samples (started with 103 participants, 76 retained for analysis after elimination of incorrect solutions) and does not rely on individual problem-solving protocols.

The results shows that, while experts have a higher rate of success, solve the problems faster and are better at planning ahead (without solving), both, experts and novices use forward inference four times more often than backward inference. The result disagrees with previous papers (Larkin et al., 1979, 1980) showing no significant difference in the order in which the problem equations are generated.

This publication, although a bit dated, will be used in the literature review to illustrate the attempts of creating an artificial intelligence to solve physics problems by simulating expert and novice problem solvers. It also shows that the results of the studies are not always clear: the results by Priest and Lindsay lead to a different conclusion than what was seen as the accepted difference between novices and experts at the time.

Smith Ill, diSessa and Roschelle (1994)

Smith III, J. P., Disessa, A. A., & Roschelle, J. (1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences*, *3*(2), 115–163.

Key-concept: *Misconceptions, Resource for cognitive growth, Novice-Expert differences*
Citation: *(Smith III, Disessa, & Roschelle, 1994)*

Smith, diSessa and Roschelle provide an overview of the research on misconceptions prior to 1994 and link it to the novice-expert differences identified in the early 1980s by Chi, Larkin and their collaborators. (M. T. Chi et al., 1981; Larkin et al., 1980).

Smith et al. critique the research to view initial student conceptions as misconceptions that need to be replaced by expert conceptions and to focus identifying on those misconceptions rather than how expertise is being developed. They argue that, in alignment with the constructivist view, prior conceptions are important resources for cognitive growth and that rather than being replaced, they are refined and reorganized. According to Smith et al., labeling the naïve conceptions, even if faulty, as misconceptions is not taking the students thinking seriously. After all, these conceptions are so widespread and resistant to change because they are effectively explaining the everyday experiences of the students.

The authors critique the problem settings used by Chi et al., Larkin et al. and others (M. T. Chi et al., 1981; Larkin et al., 1980) as well as their conclusions on the expert-novice differences. They argue that novices show much more “expert-like thinking” if they are confronted with a situation familiar to them. They use examples of novice behaviour in problematic but familiar situations, like how a bike frame is suspended, to illustrate that what appears to be a surface approach, is, in fact, a procedure not much different to those employed by experts. Experts, under closer examination, also use their prior, intuitive knowledge. The difference is that experts have refined that knowledge. Smith et al. therefore refute the conclusion that the initial concepts need to be replaced.

This paper is supporting the views brought forward by Buteler and Coleoni (Buteler & Coleoni, 2014) as well as Lin and Singh (Lin & Singh, 2015) to shift from wanting to replace initial conceptions towards refining and using them as the foundation of further knowledge. It builds a bridge between the two topics of my literature review: alternative conceptions and the difference in experts and novices approaches to problem-solving. As a side-note, the authors raise the question if simply removing the naïve conceptions from the student’s knowledge framework really has no negative impact. They leave the question open, but the answer to that question could provide much insight into how students learn when forced to ignore their alternative conceptions.

Wilson (2014)

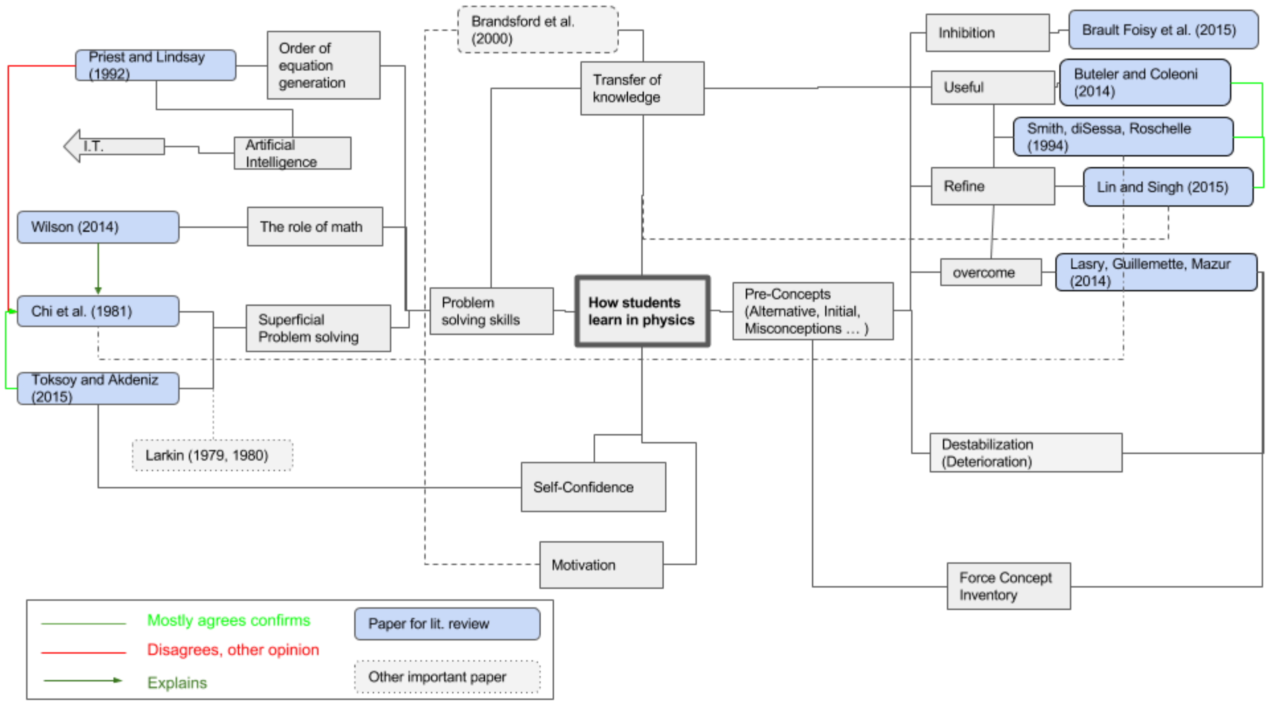
Wilson, M. (2014). Student and expert perceptions of the role of mathematics within physics. *Waikato Journal of Education, 19*(2). Retrieved from http://www.wje.org.nz/index.php/WJE/article/view/101

Key-concept: *The role of math, Novice-Expert differences*
Citation: *(Wilson, 2014)*

Wilson explores the differences of the perception of math in physics between novices and experts. Both, experts and novices, agree that physics is linked to the real world and that math can be used to show the relations between physical quantities. While the experts perceive physics as a science that is based on experiment and concept, the novices see physics as some form of applied mathematics.
Wilson argues that this view of physics is making the student's approaches to problems less effective. He supports this argument with a finding by Mazur (Mazur, 1997) : students are able to solve problems with numbers, but are clueless when the same problem should be solved based on concepts. While some of the approaches used by students to solve numerical problems correlate with those employed by experts (using math as a language to describe the situation), others ("plug-and-chug" as well as copying the steps from a similar looking problem) might work but show no awareness of the physics concepts related to the problem. Wilson used the pure existence of the force concept inventory (a concept based questionnaire without any math) to underline how well known this not-understanding of concepts is in the community. He further cites Hake (Hake, 1998), that found that traditional education results in no significant gain on the force concept inventory (FCI) performance. Another paper referred to is the work by Elby (Elby, 2001), stating that it is the focus on math in the physics courses that is holding the students back. Students with problems in math think they can never do physics and thus never will, while students that are good in math, believe that their math competencies are sufficient to master physics.

While Wilson's study, based on only 7 students and 9 experts, has a very low number of participants (especially compared to the thousands in FCI-studies (Hake, 1998; Lasry et al., 2014)), it explains an odd fact physics teachers are well aware of: Students tend to do better in numerical questions than in concept questions. By exploring the perception of the role of math, Wilson discovers a significant difference between experts and novices that could be the cause of the superficial problem-solving approach of novices observed by Chi, Feltovich and Glaser (M. T. Chi et al., 1981). Could it be, that the students, being thought not to trust their initial conceptions, abandon the concept-approach to physics altogether and replace it with a numerical math approach that we qualify as superficial? If so, then this would be a link between the two aspects of student learning I want to focus on in my literature review.

Concept map


Brandsford et al. (2000)
Priest and Lindsay (1992)
Order of equation generation
Transfer of knowledge
Inhibition
Brault Foisy et al. (2015)
Useful
Buteler and Coleoni (2014)
I.T.
Artificial Intelligence
Smith, diSessa, Roschelle (1994)
Refine
Lin and Singh (2015)
Wilson (2014)
The role of math
overcome
Lasry, Guillemette, Mazur (2014)
Chi et al. (1981)
Superficial Problem solving
Problem solving skills
How students learn in physics
Pre-Concepts (Alternative, Initial, Misconceptions …)
Toksoy and Akdeniz (2015)
Larkin (1979, 1980)
Destabilization (Deterioration)
Self-Confidence
Motivation
Force Concept Inventory
Mostly agrees confirms
Disagrees, other opinion
Explains
Paper for lit. review
Other important paper

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