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Why is learning hard?

Learning is challenging because it involves developing complex, domain-specific skills—not just absorbing information—especially in subjects like physics.

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Learning the requisite domain specific content for knowledge acquisition is the accepted primary goal of education. Since this cannot happen unless the entire content learning is cast in the framework of structured activity, we have educational institutions that offer subject specific courses leading to corresponding degrees. There have been instances where some educationists have tried to adopt a learner specific unstructured mode for learning, but these appear to work for small groups and appear non-viable for large student groups. Learning does happen outside the framework of formal classroom learning. In this article we confine our discussion to refer to subject specific formal learning which mostly happen in classrooms in educational institutions, and the process is adaptable and implementable to large population of learners. In this present context, teaching and learning indeed keeps good examination performance as the primary goal. As a result of considering performance in examination as the goal of a learner, the joy of learning takes a backseat. Passing of examination and obtaining the relevant degree appear to be the goal of learners, imparting content and domain specific knowledge effectively is the requirement from the teachers' perspective. There apparently is a mismatch of intent. If an in-depth analysis of the learners' understanding is attempted, there appear weak effectiveness of learning outcome. Education is not producing skilled personnel who can contribute to an effective societal growth.

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Learners often hold the view that a particular subject is hard and hence less appealing. The difficulty and the resulting disinterest they experience has a cumulative effect and impede further learning. Is any subject inherently difficult? The answer would depend on whom we ask this question. To the novice the subject is hard whereas to the expert it is not. For our discussion, novice is new to a particular domain or skill whereas an expert is someone with extensive knowledge, experience and skill in a specific domain. The difficulty a learner experiences in a subject will wean them away from the subject. Even those who continue learning the subject end up procuring fragmented unconnected understanding because of persistent learning difficulties. Each domain of knowledge comes with its own constructs. Learning then boils down to acquiring and mastering of the associated skill sets. No domain learning can be easy or hard. As one famous educationist put it, playing gully cricket (perceived as easy) is not the same as becoming a trained cricket professional (which is hard). Identifying the relevant skill sets and addressing modes of teaching those skill sets should then become the goal of teaching/learning and hence that of education. Domain specific education researchers have carried out extensive research in understanding the learning difficulties of students and have tried to address methods of improving effective teaching/learning. This research is more extensive in subjects that are perceived in general to be more difficult by the learner. Physics as a subject is perceived to be a difficult subject by majority learners, even by those students who have chosen it as a subject for advanced learning. There exists a large body of research that has probed various aspects of physics learning. We address impediments to learning with physics learning as an illustrative example, argue the need to relook at education as a means of identifying the necessary skills and developing methods for effective imparting of the same.

Physics learning involves several aspects as discussed below.

Conceptual understanding

Fundamental to the task of physics learning is a robust understanding of the relevant concepts. This involves at a preliminary level, 'knowing' the definition of concept/s and establishing a relationship among these, often resulting in the emergence of a physical law. Physics meaning of a concept sometimes conflict with English meaning of the word. Several physics concepts are hard to comprehend. Physics learning comes with its share of complexities and challenges associated with the understanding of physical quantities, comprehending of concepts. These challenges are often inextricably convoluted resulting in a multitude of learning difficulties. Physical quantities have non-negotiable meaning in general, a few have context dependent colloquial meaning too - for example: tension, work done and spin; while a few others have domain specific connotation - for example: internal energy, enthalpy and Fermi energy. Learners are required to integrate the sense arising from the various physical quantities at progressive stages of instruction. Conceptual understanding is central to building a robust knowledge structure. Development of conceptual frameworks to identify obstacles and challenges which students encounter when learning physics has been the focus of research initiatives in Physics Education Research (PER). Students coming into a physics classroom often hold deeply rooted and persistent, firm understandings that differ from expert conceptions. These are commonly referred to as misconceptions or alternative conceptions. Students' conceptions exist as incoherent knowledge fragments, which are strongly situated within specific contexts. Physics researchers have designed and employed concept inventories on varied topics to understand students' false conceptions/pre-conceptions. These conceptual difficulties tend to persist and influence several other aspects of learning. The difficulty students experience often is not what is perceived by the teacher. To understand what the learner perceives, they need to be probed differently. Concept inventories/assessments are instruments that have been developed to assess students' conceptual knowledge and identify concept-learning difficulties. In-depth investigation into the understanding of specific concepts like friction, buoyancy, second law of thermodynamics, Ampere's Law et al., has also been conducted. Results have revealed a multitude of misconceptions and preconceptions. Knowing that they exist and understanding the nature of difficulties is a step in developing teaching methods to minimise the same.

Math in

As we develop the conceptual framework, we need to develop relation between physical variables that represent these concepts. Physicists use mathematics to develop the quantitative content which eventually provides a concise description of physical phenomena, both in the macro world and micro world. They 'load' physical meaning on to the symbols and equations which adds a new dimension to the application of maths in physics. The precise relation between varied symbols yields a mathematical equation and its physical interpretation collectively describes a physical phenomenon. Since we use mathematics to express the relation between physical variables, we use symbols to represent physical variables. Here comes another complication. There are infinitely large number of physical variables that represent concepts, but a finite number of symbols. As consequence, there is considerable degeneracy: same symbol is often used to represent more than one physical quantity. A simple example is use of symbol h which can represent 'height' or 'planks constant' etc. The meaning is context dependent. This does result in muddled understanding. Learners often experience inherent difficulty to learn mathematics. Use of math in physics make physics learning more complex. Though mathematics is the language of physics, there are notable differences in the "language" of mathematics we use in physics in comparison to the one taught by mathematicians. A prominent difference is that physicists load meaning onto symbols that leads to how physicists and mathematicians interpret equations. Blending physical meaning with math symbols affects how we view equations with a goal to understand physical systems. In addition, the use of mathematics in physics is an aspect that needs careful consideration. A statement of relation between physical quantities, in addition must be dimensionally correct. education researchers are engaged in finding ways to enable students to map the mathematical knowledge to physics learning. The blending of physical interpretation with mathematics is significantly a more complex cognitive process than learning mathematics. Majority of the research studies in this segment reveal that students have difficulty in transfer of math elements to understand the qualitative relations in physics. Accepting the need of mathematics in learning, it is important to get across the role and use of maths in physics learning.

Multiple representation

In addition to all the above, there is yet another aspect that may interfere with physics learning. Novelty of physics as a discipline is in the use of multiple representations (verbal, pictorial/diagrammatic, mathematical and graphical) to illustrate various aspects of the underlying physical processes and to complement understanding. Each representation is expected to bring in an added dimension to understanding. For example, the motion diagram of an object falling freely under gravity represents the kinematic process and a graphical representation of velocity versus time yields information about acceleration. Quite often, a single representation is partial in terms of the information it conveys and therefore, the integration of all representations is vital to strengthen understanding. Literature on research in physics education brings to light student difficulties related to the use and interpretation of a specific representation as well as multiple representations that provide equivalent information. Substantial literature is available on representations and their affordances. Physicists use multiple representations (verbal, equation-based, pictorial, and graphical) in problem solving and considerable research work has been conducted on students' competence to switch between representations. There is no simple-minded abstract understanding of a physics concept since it is always represented in some form of representation. Therefore, being skilled in interpreting and using different representations and in coordinating multiple representations is highly valued in physics, both as a tool for understanding concepts and to facilitate deeper learning. Research engaged with representations is finding student difficulties with a specific representation primarily and use of multiple representations subsequently. There exist two categories of skills relevant to the use of external representations: Representational fluency & Representational flexibility. Representational fluency involves the ability to translate and switch between representations accurately and quickly while Representational flexibility involves making appropriate representational choices in each learning situation. Even the simple use of graphical representation is highly complex. Starting from the simple task of plotting two variables, learner is required to understand the role and meaning of slope which is related to yet another physical variable. Plotting a graph and reading from a graph are challenging skill sets. In addition, in-depth understanding of choice of representation in a situation also gives an insight in to the nature of learners.

Problem solving

Of the many components of a physics curriculum at the graduate level, significant components are content learning, problem solving. After content delivery, teachers employ problem-solving, both as an instructional and assessment tool. A problem has a task defined in the statement and problem-solving is a reasoning process which requires the use of qualitative and quantitative knowledge towards constructing a rational solution. Physics problem-solving comprises of application of concepts and /or the use of math tools in each problem-context. An essential characteristic of a problem solver is to retrieve/activate the relevant schema corresponding to a problem from declarative memory and decide on the procedural rules to complete the solution. We would like our students to learn the components of successful problem solving which are:

- Ability to identify (and connect) the relevant physics concept/s
- Ability to comprehend and navigate between multiple representations
- Ability to use mathematical tools required
- Ability to evaluate the solution

Though the above-mentioned skill/s are vital for solving typical end-of-chapter problems which do not necessarily reflect scientific thinking, these will be tested in greater depths in altered contexts of physics problems. Given that physics learning encompasses a multitude of phenomena and concepts, a pertinent question that needs to be addressed from a teacher's perspective is whether the skills can be taught explicitly to students through problem-solving frameworks.

From learning content to its effective use in each context, teaching boils down to training learner in domain specific skill sets. These skill sets can not be taught as a stand-alone entity. They can be illustrated only when embedded in the content. Teaching the content therefore always involves an effort to understand the relevant skill that is embedded in the content. Though the entire discussion in this article is related to physics as the subject of interest, similar issues are relevant for learning in any domain. The skill sets needed for learning is different and the learning difficulties are of a different nature. Teaching/learning is an act of imbibing the relevant skill sets which then is enveloped by the domain specific content. Teaching is not a mere transfer of content. Even in situations where the learner has the interest, intent and the teacher has the content expertise, learning is not a simple task. Leaning outcomes become robust only by viewing teaching as a means of enabling the learner with the necessary domain specific skills.

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