The Outcomes of the Learning Curve for a Concept in Physics Education

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Abstract

A learning curve is an old tool recently used in physics education. The curve describes the relationship between the learning gained and the time invested in the learning process. This paper discusses the meaning of the learning curve in physics education and reviews the model of the learning curve and possible applications in physics education. It also discusses some factors influencing the learning curve, such as prior knowledge, motivation, and teaching strategies. Finally, the paper explores the concept of the learning curve in physics education, its significance, and its applications in teaching and learning.

Keywords: Learning curve, misconceptions, physics education.


Introduction

Learning is the process of acquiring new knowledge, skills, or behaviours. It is a fundamental aspect of human development and is essential for growth and personal evolution. The learning process can occur in various forms (Lave, 1982), such as formal education, self-study, and practical experience. The learning process typically begins with an initial phase of exposure or acquisition of information. This phase involves receiving information through various channels (Simons et al., 2000), such as reading, listening, observing, or acting. The information obtained in this phase serves as a foundation for subsequent learning activities. It is crucial to pay attention and focus during this phase to ensure that the information is accurately received. Once the information is acquired, the next phase involves the retention and processing of this information. This phase is critical because it determines how much the information will be retained in long-term memory. Information processing can be enhanced by various techniques such as repetition, active engagement, and association with previous knowledge. A critical factor in this phase is the ability to make connections between different pieces of information, which can facilitate the creation of a meaningful framework for understanding (Van Den Broek et al., 2005). After the retention phase, the next stage is applying or utilising the information (Song, 2005). This phase involves actively using knowledge or skills to achieve a particular goal or task. This stage is essential because it enables the learner to gain practical experience.
and develop problem-solving skills. Successful learning also depends on several factors, including motivation, feedback, and the learning environment (Liñán, 2011). Motivation is crucial because it determines the level of effort and engagement a learner puts into learning (Entwistle, 1988; Saeed & Zyngier, 2012). Feedback from peers, instructors, or self-evaluation provides learners with information on their progress and areas that need improvement. The learning environment can also impact the learning process, as an environment conducive to learning can improve the learner’s engagement and focus (Wierstra et al., 2003; Vermeulen & Schmidt, 2008). Learning is a complex process that involves several stages, including acquisition, retention, and application of knowledge and skills. Successful learning is influenced by various factors such as motivation, feedback, and the learning environment. Understanding the learning process (Entwistle & Ramsden, 2015) and factors contributing to successful learning can help individuals maximise their learning potential and achieve their personal and professional goals.

Physics is the branch of science that studies matter, energy, and its interactions. Learning physics is essential for understanding the world around us, and it has critical applications in fields such as engineering, medicine, and technology. Learning physics involves acquiring knowledge, concepts, and skills related to the laws of nature, their applications, and the methods used to study them. Physics education aims to help students develop a deep understanding of the physical world and its principles (McDermott, 2004) and to equip them with the skills and knowledge needed to apply these principles to solve real-world problems. Physics education aims to teach learners how to observe (Darmajiet et al., 2019), think, and reason critically and logically about the physical world around them. There are several key concepts and skills that learners need to master to succeed in physics education. These include developing a solid foundation in mathematics, such as algebra, calculus, and geometry, and learning about fundamental concepts, such as mechanics, electromagnetism, thermodynamics, and quantum mechanics. Additionally, learners must develop various critical thinking skills, such as problem-solving, data analysis, and experimental design. One of the most significant challenges in physics education is that the concepts can often be abstract and complex to visualise (Olympiou et al., 2013). As such, effective physics education requires a combination of both theoretical and practical learning approaches. Theoretical learning involves teaching learners about the fundamental principles of physics and developing a solid understanding of the underlying concepts. On the other hand, practical learning involves hands-on experimentation and observation (Hoover, 2012), allowing learners to apply theoretical concepts to real-world scenarios. Furthermore, physics education must be tailored to each student’s learning styles and needs. This may involve using visual aids such as diagrams and models to help students understand complex concepts or providing additional one-on-one support to students struggling with specific topics. Several approaches to teaching physics have been developed over the years. One of the most effective methods is hands-on, inquiry-based learning (Huber & Moore, 2001; Saad, 2020), where students are encouraged to explore physics principles through experimentation and discovery. This approach allows students to develop their understanding of physics concepts and principles and apply them to real-world situations. Another approach is problem-based learning (Newman, 2005; Savery, 2015), where students are given challenging problems to solve and are encouraged to apply their knowledge of physics to find solutions. This approach promotes critical thinking and problem-solving skills and helps students develop a deep understanding of physics principles. In addition to these methods, physics education involves using technology and simulations to enhance learning.
(Chang et al., 2008; Banda & Nzabahimana, 2021). Computer simulations can be used to model complex physical systems and phenomena that are difficult to observe or measure directly (Morrison, 2009). This approach allows students to explore and manipulate these systems and to develop an intuitive understanding of their behaviour. Recent technological advances have also revolutionised physics education (Saphira et al., 2023; Yeadon et al., 2023). Online learning platforms, simulations, and virtual reality tools (Phanphech et al., 2022) have made physics education more accessible and engaging, allowing learners to explore and experiment with physics concepts in a safe and controlled environment. Physics education requires a combination of theoretical and practical learning approaches. Effective physics education requires a strong foundation in mathematics, critical thinking skills, and tailored approaches that meet each student's unique learning styles and needs. By providing a solid foundation in physics, learners can better understand the world around them and make meaningful contributions to science and technology. By combining hands-on, inquiry-based learning, problem-based learning, technology, and mathematical reasoning, students can develop a deep understanding of physics principles and their applications.

The Learning Curve

The learning curve is a graphical representation of the progress of learning, and it provides insights into the effectiveness of instructional strategies, the learners' abilities, and the learning outcomes. The learning curve is a concept that describes the relationship between experience and performance in a task. The term originated in the field of psychology (Chapman, 1919), where it was used to describe the rate at which individuals improve their skills or tasks over time. The curve typically starts with slow progress at the beginning of the learning process, followed by a steep increase in learning (Thurstone, 1919). Eventually, a plateau in which further improvement becomes more difficult. The learning curve can vary greatly depending on the individual and the learned skill. Some people may have a steep learning curve and quickly acquire new skills, while others may have a more gradual curve and require more time and practice to reach the same level of proficiency (Gallistel et al., 2004). Several factors can influence the shape of the learning curve (Viering & Loog, 2022). These include motivation, previous experience with similar tasks, the skill's complexity, and the quality and quantity of feedback provided during the learning process. Research has shown that various instructional strategies can influence the learning curve (Friedrichsen et al., 2009). For example, breaking down a complex task into smaller, more manageable steps can help individuals learn more quickly and effectively (Shail, 2019). Providing frequent feedback and opportunities for practice can also help individuals improve their performance more rapidly. Understanding the learning curve is essential for educators and trainers in various settings, including schools, businesses, and sports teams. By understanding the factors influencing the learning rate, instructors can develop more effective teaching strategies and help individuals reach their full potential.

In education, the learning curve is a crucial factor in determining the effectiveness of a curriculum, teaching methods, and student progress. The learning curve has been used chiefly in health professions education for years (Pusic et al., 2015). A learning curve in medical education refers to acquiring new knowledge, skills, and competencies.
through practice and experience. This curve is typically represented graphically, with the vertical axis indicating the level of proficiency or competency and the horizontal axis indicating the amount of time or experience. At the beginning of their medical education, students often have limited knowledge and skills, and their learning curve is steep as they rapidly gain new knowledge and experience (Persky et al., 2015). As they progress through their training, their learning curve may plateau as they become more proficient in medicine’s basic concepts and skills (Heiferman et al., 2023). However, as they encounter more complex and challenging cases, their learning curve may once again steepen as they acquire new knowledge and skills. The learning curve is essential in designing educational programs and assessing student progress in medical education. Educators may use the learning curve to identify areas where students are struggling and to provide targeted support and feedback to help them improve. They may also use the learning curve to set expectations for student performance and evaluate the effectiveness of educational interventions. The learning curve in medical education (Yeolekar & Yeolekar, 2015) is a dynamic and ongoing process reflecting the complex and evolving nature of medical knowledge and practice. As medical students progress through their education and training, they must continuously adapt and learn to keep pace with new developments and provide their patients with the best possible care. Especially in surgery, the learning curve is crucial to medical education (Hopper et al., 2007). Surgical trainees need to gain experience and practice under the supervision of experienced surgeons to acquire the necessary skills and knowledge to perform surgeries effectively and safely. The learning curve can also impact patient outcomes, as surgical errors and complications are more likely to occur during the early stages of a surgeon’s learning curve. The learning curve in surgery can be steep (Sturman et al., 2017), meaning that a significant amount of practice and experience is required before a surgeon becomes proficient in performing a particular surgical procedure. This is especially true for complex surgical procedures, such as open-heart surgery, where the learning curve may be longer and steeper than for less complex procedures. To overcome the learning curve in surgery, surgical trainees need to engage in deliberate practice involving focused and repetitive practice with feedback and reflection (McGaghie et al., 2010). Surgical training programs often include simulation-based training, which allows trainees to practice procedures in a controlled environment before performing them on actual patients. In addition, mentorship and supervision by experienced surgeons can help trainees overcome the learning curve more quickly and safely. In conclusion, the learning curve in medical education, specifically in the surgery sector, is essential to acquiring the traditional ones (Stambough et al., 2020).

The learning curve is also used for constructing robots, and it is crucial, especially in the machine-learning sector (Perlich, 2010; Richter & Khoshgoftaar, 2019). In 2010, Leibowitz et al. published an interesting paper describing the learning curve’s shape depending on the number of failed or successful trials. They were trying to train a robot in the same way that a human being is learning. Their result was that the learning curve is exponential if a person has only failures. If a person has only success trials, the learning curve is sigmoid. In real life, a person learns with a combination of failures and successful trials, so the learning curve is between an exponential and a sigmoid one. In all cases, the learning curve is a graphical representation of the relationship
between the amount of learning gained and the time invested in the learning process. It typically shows a steep increase in learning at the beginning of the learning process, followed by a plateau where the learning rate slows down. Finally, there is a gradual decline in the learning rate as the learner approaches mastery of the topic.

The shape of the learning curve, Figure 1, can vary depending on several factors, including the learner's background knowledge, motivation, instructional strategies, and the complexity of the learning material. Several factors influence the shape of the learning curve in education. The learner's background knowledge is a crucial factor in determining the initial slope of the learning curve. Learners with more prior knowledge of the topic tend to learn faster than those without prior knowledge. Motivation is another factor that affects the shape of the learning curve. Learners motivated to learn tend to have steeper learning curves than those without motivation. Instructional strategies also play a critical role in shaping the learning curve. Strategies that promote active engagement, such as inquiry-based learning, tend to result in steeper learning curves than traditional lecture-based teaching. Finally, the complexity of the learning material can also affect the shape of the learning curve. Complex topics may require more time and effort, resulting in a flatter learning curve.

The Learning Curve in Physics Education

In physics education, the role of misconceptions in the learning process is well known (Driver, 1989; Hammer, 1996). Misconceptions are common misunderstandings that students may have about a concept (Stylos et al., 2021; Stylos & Kotsis, 2023), and they can reveal areas where students need additional support or clarification. By identifying misconceptions, teachers can assess the effectiveness of their teaching methods and
adjust as needed (Vosniadou, 2020). By addressing misconceptions, teachers can gain insights into what students already know (or think they know) and where they are having difficulties. This information can then be used to adjust teaching strategies, focus on areas of difficulty, and help students connect their prior knowledge and the new concept being taught. Even today, there are many studies about physics misconceptions (Soeharto et al., 2019; Bao et al., 2019; Gavrilas et al., 2022; Stefanou, 2023). All the effort in physics education is to achieve conceptual change, but the resistance to misconceptions is strong and makes learning difficult (Kotsis, 2011). Students learn science when discovering, understanding, and applying scientific concepts and theories (Lombardi, 2021). This process typically involves the following steps:

- Observing: The student observes phenomena and asks questions about what they see. This can involve experiments, field studies, or observing the natural world.
- Questioning: The student asks questions about what they observe and seek answers to their questions. They may use curiosity, intuition, and prior knowledge to form hypotheses and theories.
- Researching: Students research scientific literature, conduct experiments, and collect data to support or disprove their hypotheses. They may also use online resources, textbooks, and scientific simulations to gain more knowledge.
- Analysing: The student analyses data, interprets results, and forms conclusions based on their findings. They may communicate their findings using mathematical models, graphs, and visual representations.
- Communicating: The student is communicating their findings to others, either through written reports, oral presentations, or other forms of media. They may also engage in discussions and debates with their peers and teachers to refine their understanding of science.

The student or a person gains scientific knowledge through this process and develops critical thinking, problem-solving, and a scientific mindset. This student starts to learn by changing his misconceptions about physics concepts with scientific knowledge (Resbiantoro, 2022). Many studies show the existence of misconceptions about physics concepts, not only among primary school students (Gilbert, 1982; Pine, 2001) but also among high school and university-level students (Bayraktar, 2009); Stylos et al., 2010). Additionally, adults, even teachers, have misconceptions about the concepts of physics (Kruger, 1990; Kotsis & Panagou, 2023a). The age at which the conceptual change starts differs for all students and depends on many factors, including the student’s mental age (Kotsis & Stylos, 2023).

Recently published two studies where the learning curve for the concept of force (Kotsis & Panagou, 2022) and the concept of energy (Kotsis & Panagou, 2023b) are determined using the misconceptions of the concepts. Tracking students' misconceptions over time can determine the learning curve for the concept. Students’ understanding of the concept and the presence of misconceptions can change over time with instruction and practice. By regularly assessing students’ misconceptions and addressing them promptly, teachers can help ensure that students develop a deep, accurate understanding of the concept and monitor their progress toward mastery. These two studies track the misconceptions for various age groups. Primary school students, middle and high school students, university students, and primary education
teachers from 25 to 55 years old. The commonality in all groups is that the persons are somehow involved with the physics course.

In both cases, the learning curve is a sigmoid one that, according to the paper of Leibowitz et al. in 2010, means that a person learns these concepts of physics after a combination of failures and successful trials. We can understand this result since all the effort in an educational system combines failures and successful trials, but these learning curves for the first time prove this well-known result.

A close look at the learning curves of the force, figure 2, and energy, figure 3, shows some differences. The plateau for the energy is a lower value than the plateau for the force. Also, there is another difference between the two learning curves. The learning curve for the concept of force starts to change the slope at a lower age than the learning curve for the concept of energy. That means that the conceptual change can start at 12 years for the force since the energy starts at 15 years old.
The difference between these two learning curves means that more people have the correct meaning of the concept of force than the correct meaning of the concept of energy. Also, at a later age, someone can understand the concept of energy than the concept of force. In other words, someone can say that the concept of force is easier to learn than the concept of energy, which is difficult. All the physics teachers know this result very well from their experience, but it is the first time this result has been found from the empirical data from scientific research using the learning curve. This means that the learning curve is a crucial concept that describes the relationship between the amount of learning gained and the time invested in the learning process.

**Conclusion**

This paper explores the meaning of the learning curve in education based on misconceptions about physics concepts, its significance in the learning process, and its implications for teaching and learning. Beneficial results come from the learning curve. The first is how difficult a concept is. A second result of the learning curve is, at what age is it better to start the conceptual change for a physics concept? There are a few factors influencing the learning curve of a concept in physics education:

- Cognitive abilities such as working memory, attention, and reasoning skills can significantly affect the learning curve in physics education. Research suggests that students with higher cognitive abilities tend to have steeper learning curves, as they can process and retain information more efficiently.

- Prior knowledge serves as the foundation for learning new concepts in physics. Students with a strong background in mathematics and science often have a smoother learning curve, as they can relate new information to their existing knowledge.

- Motivation is a critical factor in determining the shape of the learning curve. Students who are intrinsically motivated and find physics interesting tend to have a more rapid learning rate than extrinsically motivated students who lack interest in the subject.

- Instructional methods and strategies can significantly influence the learning curve in physics education. Active learning approaches like problem-based, inquiry-based, and collaborative learning have facilitated steeper learning curves than traditional lecture-based methods.

All these factors must determine how they influence a physics concept's learning curve. For the two concepts showing the learning curves in this paper, the learning curves show that the conceptual change for the concept of the force must start at 10-11 years old and for the concept of the energy at 16-17 years old. Of course, these results need additional studies, but in principle, they show that the learning curve for a Physics concept will be a handy tool to examine how the student is learning.

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**Conflict of interests**

No conflict of interest.
References


Saad, A. (2020). Students’ computational thinking skill through cooperative learning based on hands-on, inquiry-based, and student-centric learning...


