Assessing introductory physics students' learning strategies

T. M. Seixas[1], M. A. Salgueiro da Silva[2]

[1]Department of Physics and Astronomy, Faculty of Sciences, University of Porto, Rua do Campo Alegre, 687, 4169-007 Porto, Portugal and Centre for Earth and Space Research of the University of Coimbra (CITEUC), Av. Dr. Dias da Silva, 3000-134 Coimbra, Portugal

[2]Department of Physics and Astronomy, Faculty of Sciences, University of Porto, Rua do Campo Alegre, 687, 4169-007 Porto, Portugal and Centre for Earth and Space Research of the University of Coimbra (CITEUC), Av. Dr. Dias da Silva, 3000-134 Coimbra, Portugal

[1]tmseixas@fc.up.pt

ABSTRACT

This study examines physics students' learning strategies in an introductory physics course, from two sciences programs at the Faculty of Sciences of the University of Porto in Portugal, using Pintrich (2000) model of self-regulated learning (SRL). Physics II is an introductory course addressing fundamental principles of electricity, magnetism, optics, and thermodynamics. The research instrument used in this ongoing study involves two open-ended questions on learning strategies used by students to study the Physics II course and the percentage of the strategy's first rank choice. The three most listed students' learning strategies were: "to study course materials", "to solve problems" and "to do online formative tests" – for most students, these were ranked as the first choice. Some of the referred learning strategies by students belong to metacognitive knowledge. To a broader understanding of the qualitative results, a quantitative analysis must be performed and extended beyond undergraduate students from physics to postgraduate students enrolled in Master's degrees of physics, mathematics, and engineering. Moreover, for a deeper understanding of the various areas of SLR phases, the area examined must be expanded to analyse motivations, behaviour, and context, and not only the metacognition area.

Keywords

physics learning, learning strategies, metacognitive knowledge, Vygotsky, self-regulated learning (SRL)

Article Received: 10 August 2020, Revised: 25 October 2020, Accepted: 18 November 2020

Introduction

Human cognitive architecture refers to how cognitive structures are arranged (Anderson and Krathwohl, 2001). University education calls for the development of higher-order types of knowledge, such as factual, conceptual, procedure, and metacognitive. According to Karpov (2014) *factual knowledge* is the knowledge of clear facts, names, dates, and so forth. It is important for understanding a scientific text or memorizing new information. Factual knowledge creates a background of basic elements students must know to be acquainted with a discipline or problem solving in it. It includes knowledge of terminology and specific facts. Some examples of factual knowledge: Paris is the capital of France; the Big Ben is in London; my cat is a mammal; these two lines are called perpendicular; Earth is a planet; an ingot of lead put in water, will sink.

Conceptual knowledge (Karpov, 2014) is the knowledge of concepts, principles, theories, and the like. Arslan (2010) stated that conceptual knowledge is the learning that involves understanding and interpreting concepts and the relation between concepts. The following statements given by Karpov (2014) represent examples of conceptual knowledge: "president – the leader of a country elected by citizens for a set period of time; mammals – vertebrate, warm-blooded animals that feed their babies milk; objects with a density greater than the density of water will sink; two straight lines that meet at right angle are called perpendicular". Conceptual knowledge consists of the interrelations among the basic elements within a larger structure that enable them to function together (Anderson et al., 2001, p. 29). According to Karpov (2014) conceptual knowledge permits a description of classes and phenomena and, therefore, is a psychological tool that can be called for thinking and problem solving. Despite the generalizations based on essential characteristics of objects and phenomena characteristic of conceptual knowledge, misconceptions are often developed, based on so-called correlational characteristics. For example, although students might have learned correct conceptual knowledge, will they be able with this knowledge to solve subject domain problems? Karpov (2014) supported his answer using Vygotskyan (Vygotsky, 1986, original work published in 1934) arguments drawn from the analogy between labour's tools and psychological tools: "to be able to hammer in a nail, it is not sufficient to have a hammer; one also needs to master the proper procedure of its use; the knowledge of a concept by itself does not guarantee that one can use this concept to solve problems. Thus, just as you cannot use a hammer if you have not mastered the procedure of its use, you cannot use conceptual knowledge as psychological tool for thinking and problem solving if you have not mastered the relevant procedural knowledge."

Procedural knowledge is the type of knowledge exercised in the performance of a task (Karpov, 2014). It's basically "how" you know to do something. It is the type of knowledge exercised in the performance of a task. For example, to find out if an ingot of lead will sink in water, a student will have to compare the density of lead with that of water, to find out if the density of lead is greater (lead will sink) or smaller than the density of water. Another example, to find out if two straight lines are perpendicular to each other, a student must check out whether or not the two lines meet at an angle of ninety degrees (90º). But students may become quite proficient at procedure, but not understand why it works and when it should be used. Physics students may learn how to solve standard problems in different areas of physics, without understanding why the procedure works; students might just use it to solve similar physics problems, that were given by the teacher when illustrating the procedure at classes. So, this procedural knowledge is not transferable. How should physics classroom practices be adjusted to ensure that procedural knowledge that students acquire is transferable? Again, Vygotskyan (Vygotsky, 1986, original work published in 1934) arguments supported the answer, with the following statement being representative of it: “teaching students a combination of procedural and conceptual knowledge.” In order to make procedure meaningful and transferable, conceptual knowledge and subject domain procedure are learnt together (Leontiev, 1983), (Bruer, 1993). In this way students are acquainted to use the procedure in unfamiliar and novel situations, namely to solve physics domain problems.

Brown (1987) argued that *Metacognitive knowledge* “refers to what we know about our own cognitive processes” (Brown, 1987). It refers to knowledge of skills and strategies that an individual may employ in solving a problem. Karpov (2014) argued that metacognitive knowledge is described “as our ability to self-regulate: to plan and monitor our behaviour and to evaluate its outcomes”. According to Flavell (1979), in the deepest meaning of this word, metacognition also includes the knowledge of how the human cognition works. Hewitt (1983) claimed that students at different academic stages are supposed to develop self-regulation to an even higher level, in order to master their thinking, learning and problem solving; therefore, Hewitt argued that students should be encouraged to use critical thinking during physics problem solving. Karpov (2014) pointed out the importance of metacognition studies in intelligent novices, those who have a high metacognition knowledge, but no knowledge in a specific subject; this lack of specific subject knowledge is compensated by the good metacognitive knowledge. Usually, successful and unsuccessful students are differentiated on the base of this knowledge.

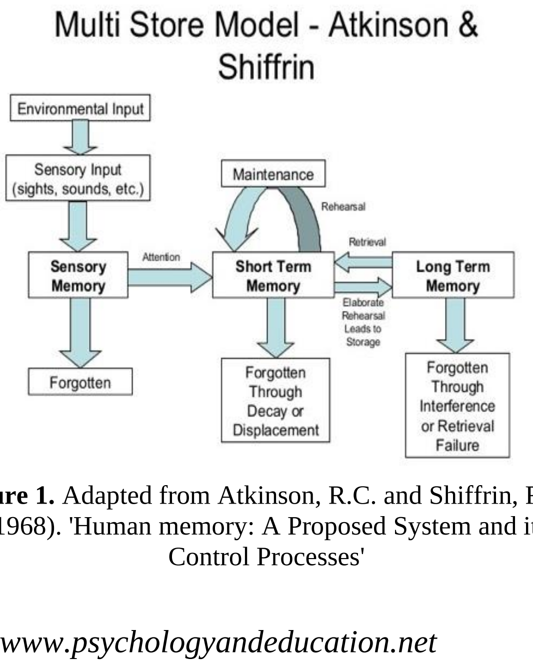

Figure 1. Adapted from Atkinson, R.C. and Shiffrin, R.M. (1968). 'Human memory: A Proposed System and its Control Processes'

To teach university students, it is not enough to lecture them with the knowledge the instructor wants them to learn. Instructors should support students throughout the entire process as well, which implies helping students during acquisition, mastering and memorization. Therefore, according to the model of information processing proposed by Atkinson and Shiffrin (1968), for information to be strongly implanted in memory it must pass through three stages of mental processing: sensory memory, short-term memory, and long-term memory (see Fig. 1 for a simplified version of the model). As a student takes in information, that information is first briefly stored as sensory register, the Sensory Memory (examples: listening to an instructor or smelling a classmate’s perfume); then moved to the Short-Term Memory (or working memory); and then either forgotten or transferred to the Long-Term Memory, as semantic memories (concepts and general information), procedural memories (processes) or images. Karpov (2014) stated that the information moved into this working memory are maintained there for only about 20 seconds, except in the so-called rehearsal (repeating and repeating information), where the time duration can be prolonged. The main function of this working memory is the processing of deep information, or in other words, the thinking. As claimed by Smirnov (1948) and other American cognitive psychologists (Ormrod, 2008), (Otterman, 2011), (Stipek, 2002), and Vygotskyans (Smirnov, 1948) when talking about successful learning, it is important the engagement of students in the performance of a task that requires deep processing of the material. Cognitive load theory suggests that learners can absorb and retain information effectively only if it is provided in such a way that it does not “overload” their mental capacity (Bloom et al., 1956). In summary, learning is what is happening when our brains receive information, record it, mould it and store it.

According to Panadero (2017) self-regulated learning (SRL) is a “core conceptual framework to understand the cognitive, motivational, and emotional aspects of learning”. Following this model, SRL is composed by four phases: (1) Forethought, planning and activation; (2) Monitoring; (3) Control; and (4) Reaction and reflection. “Each of them has four different areas for regulation: cognition, motivation/affect, behaviour and context. That combination of phases and areas offers a comprehensive picture that includes a significant number of SRL processes (e.g., prior content knowledge activation, efficacy judgments, self-observations of behaviour)”.

Research Methodology

According to Branslord et al. (1999), Cañas (2003), Siew (2019), Amer (2006), Rosell-Tarrago et al. (2018), and Vukic et al. (2020) students as individuals differ in their ability to learn from experience, to adapt to new situations and overcome challenges, to understand simple or complex ideas, to solve real-world or abstract problems, and to

engage in different forms of reasoning and thinking. Knowledge acquisition and integration activities are designed to help learners construct a more coherent understanding by developing criteria for the ideas that they encounter.
This study reports a descriptive qualitative ongoing research that draws on the understanding of learning strategies used by freshmen students from an introductory physics course (Physics II), enrolled in two different programs, Environmental Sciences and Technology, and Chemistry at the University of Porto, using Pintrich (2000) model of SRL.

2.1 Population

The study's population had 128 first-year students from Physics II course, with 64 students from Environmental Sciences and Technology (EST) degree and 64 students from Chemistry (C) degree, at the Faculty of Sciences at the University of Porto, in Portugal. The sample period was the 2018/19 academic year. Participants' gender was nearly evenly distributed, namely with 56% female and 44% male.

2.2 Research Procedure and Instrument

The Physics II course is a general introductory course, where fundamental principles of electricity, magnetism, optics, and thermodynamics are covered. The classes develop conceptual, calculation, and problem-solving skills focused on physical and mathematical topics required for underpinning physical laws. In seminar classes, a cooperative problem-solving instructional strategy is used.
The research instrument used in this qualitative study consisted of two open-ended questions closely adapted from an experimental study by Karpicke et al. (2009) and a work by Cervin-Ellqvist et al. (2020). The qualitative survey was conducted face-to-face in campus setting and participant students were randomly selected.
Open-Ended-Question A: "What learning strategies did you use for studying for Physics II course? Rank your answers by the most used one."
Open-Ended-Question B: "List two main reasons for your three first choices on learning strategies."

Results and Discussion

The students' responses to open-ended-question A on learning strategies is depicted in Tab. 1. Percentages of the seven most listed learning strategies are shown in Tab. 1 and percentage of the first rank strategy as well.

Table 1. The seven most listed students' learning strategies (%) and the first rank strategy (%)

Learning strategy	Students percentage (%)	First rank strategy (%)
To study course materials	98	90
To solve problems	87	76
To discuss cooperatively with others	45	1
To do past papers	69	79
To do online formative tests	90	89
To answer quizzes	30	1
To study bibliography	10	6

Examples of students' responses to open-ended-question B, referring different reasons for their learning strategies' choice and corresponding ranking, are listed below:
- "the course materials are well elaborate";
- "the course materials are synthetic and sufficient for an overall comprehension";
- "cooperative discussions help to overcome difficulties";
- "bibliography helps to study difficult and hard contents of the course";
- "answering quizzes helps in preparing for the exam";
- "online formative assessment tests help to bolster confidence";
- "doing past exams improves confidence"

Qualitative data were analysed using inductive thematic analysis (Braun & Clark, 2006), similar to Cervin-Ellqvist et al. (2020) procedure. Fig. 2 shows a comparison between the reasons referred by students in their learning strategies' choices and Pintrich (2000) model of SRL encoded through inductive analysis.
The three most listed students' learning strategies, with a percentage above 85%, are: "to study course materials" (98%), "to solve problems" (87%) and "to do online formative tests" (90%). These strategies are ranked as first choice with the following percentages, respectively: 90%, 76% and 89%.
The learning strategy "to study course materials" is dominated by 55% of "mi – it includes the most important/most relevant information", followed by 25% of "co – to increase comprehension". The learning strategy "to solve problems" is equally dominated by 35% of both "te – to identify/test what one knows/comprehends and not" and "ii – to identify what one is supposed to know/what is important", which could be related to the use of metacognitive knowledge. The learning strategy "to do online formative tests" is dominated by 35% and 25% of "ex – to learn about the exam" and "te – to identify/test what one knows/comprehends and not", respectively. Moreover, it is the only strategy that encompasses all five inductive thematic analysis considered in this study. The "ii – to identify what one is supposed to know/what is important" is the only inductive theme transverse to all learning strategies.

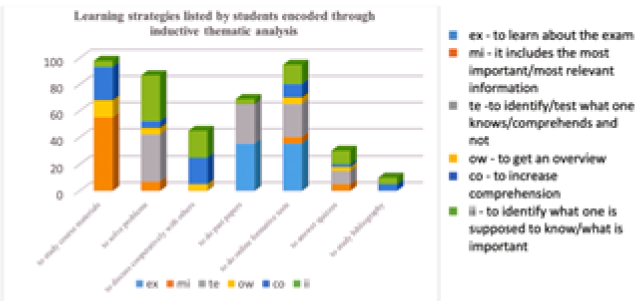

Figure 2. Learning strategies listed by students encoded through inductive thematic analysis through Pintrich's model of SRL (based on Cervin-Ellqvist et al. (2020)).

Conclusion and Future Work

The three most listed students' learning strategies, with a percentage above 85%, are: "to study course materials" (95%), "to solve problems" (87%) and "to do online formative tests" (90%). These strategies are ranked as first choice with the following percentages, respectively: 90%, 76% and 89%.

Some of the learning strategies mentioned by students belong to metacognitive knowledge: "ow – to get an overview", "co – to increase comprehension", "te – to identify/test what one knows/comprehends and not". The last one dominates the learning strategy "to solve problems" and is second ranked in "to do past papers" and "to do online formative tests". The metacognitive knowledge "co – to increase comprehension" is also used by students during the learning strategy "to study course materials".

It must be highlighted that students used the learning strategy "to discuss cooperatively with others" as a metacognitive strategy to "ow – to get an overview", to "co – to increase comprehension" and to "ii – to identify what one is supposed to know/what is important", which matches the main areas of the Pintrich's (2000) SRL model.

To sum up, this study draws on learning strategies' choices that students from an introductory Physics course of two different programs, Environmental Sciences and Technology and Chemistry, at the University of Porto, used to learn during the course. They revealed a metacognitive knowledge under the Pintrich's (2000) SRL model. For a broad understanding of these qualitative results, a quantitative analysis must be performed in the near future and extended not only to introductory physics students but also to advanced students enrolled in major and master in physics, mathematics and engineering. In addition, to deeply understand the different areas for regulation of SRL phases, not only the metacognition area must be examined, but also motivation/affect, behaviour and context.

Acknowledgments

Authors would like to thank FCUP's participant students for their contribution in the data collection. Informed consent was obtained from all participant students included in this study. This work was carried out under project POCI-01-0145-FEDER-006922 funded by FCT/MEC (PIDDAC) and FEDER – European Regional Development Fund through COMPETE 2020 – Operational Programme Competitiveness and Internationalization..

References

[1] Amer, A. (2006). Reflections on Bloom's revised taxonomy. Electronic Journal of Research in Educational Psychology, vol. 4, no. 1, pp. 213–230.

[2] Anderson, L. W. and Krathwohl, D. R. (2001). A Taxonomy for Learning, Teaching and Assessing: a revision of Bloom's taxonomy of educational objectives, Abridged Edition, Addison Wesley Longman, Inc., NY, USA.

[3] Arslan, S. (2010). Traditional instruction of differential equations and conceptual learning. Teaching Mathematics and Its Applications, vol. 29, pp. 94-107.

[4] Atkinson, R. C. and Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.). The psychology of learning and motivation, vol. 2, pp. 89-195, NY: Academic Press.

[5] Bloom, B., Englehart, M., Furst, E., et al. (1956). Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: Cognitive Domain, Longmans Green & Co., New York, USA.

[6] Branslord, J. D., Brown, A. L. and Cocking, R. R. (1999). How People Learn: Brain, Mind, Experience and school, National Academy Press., Washington, DC, USA.

[7] Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, vol. 3(2), pp. 77. https://doi.org/10.1191/1478088706qp063oa

[8] Brown, A. L. (1987). Executive Control, Self-Regulation, and Other More Mysterious Mechanisms. F.E. Weinert, R. Kluwe (Eds.), Metacognition, Motivation, and Understanding, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 65-116.

[9] Bruer, J. T. (1993). Schools for thought: A science of learning in the classroom. Cambridge, MA: MIT Press.

[10] Cañas, A., Coffey, J., Carnot, M. and Feltovich, P. J. (2003). A summary of literature pertaining to the use of concept mapping techniques and technologies for education and performance support. Technical Report, Chief of Naval Education and Training, Pensacola, FL, USA.

[11] Cervin-Ellqvist, M., Larsson, D., Adawi, T., Stöhr, C., Negretti, R. (2020).

Metacognitive illusion or self-regulated learning? Assessing engineering students' learning strategies against the backdrop of recent advances in cognitive science. Higher Education. https://doi.org/10.1007/s10734-020-00635-x.

[12] Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive -development inquiry. American Psychologist, vol. 34, pp. 906-911.

[13] Karpicke, J. D., Butler, A. C., and Roediger, H. L., III. (2009). Metacognitive strategies in student learning: do students practise retrieval when they study on their own? Memory, vol. 17(4), pp. 471–479. https://doi. org/10.1080/09658210802647009.

[14] Karpov, Y. V. (2014). Vygotsky for Educators, Cambridge University Press, NY, USA.

[15] Leontiev, A. N. (1983). Selected Works in Psychology, vol. 1, pp. 324-347. Moscow: Pedagogika.

[16] Ormrod, J. E. (2008). Human learning. Upper Saddle River, NJ: Prentice-Hall

[17] Otterman, S. (2011). Ed. Schools' pedagogical puzzle. The New York Times, July 21. Retrieved from: http:/www.nytimes.com/2011/07/24/education/edlife/edl-24teacher-t.html?_r=1&ref=sharonotterman.

[18] Panadero, E., (2017). A Review of Self-regulated Learning: Six Models and Four Directions for Research. Front Psychol, vol. 8, pp. 422.

[19] Pintrich P. R. (2000). The role of goal orientation in self-regulated learning, in Handbook of Self-Regulation, eds Boekaerts M., Pintrich P. R., Zeidner M. (San Diego, CA: Academic Press), pp. 452–502.

[20] Rosell-Tarrago, G., Cozzo, E. and Diaz-Guilera, A. (2018). A complex network framework to model cognition: unveiling correlation structures from connectivity. Complexity, vol. 2018, Article ID 1918753, 19 pp.

[21] Siew, C. S. Q., Wulff, D. U., Beckage, N. M. and Kenett, Y. N. (2019). Cognitive network science: a review of research on cognition through the lens of network representations, processes, and dynamics. Complexity, vol. 2019, Article ID 2108423, 24 pp.

[22] Smirnov, A. A. (1948). Psychology of memory. Moscow. Recall for words as a function of semantic, graphic, and syntactic orienting tasks, vol. 12, pp.471-480.

[23] Stipek, D. (2002). Motivation to learn: Integration theory and practice. Boston, MA: Allyn and Bacon.

[24] Vukic, D., Martincic-Ipsic, S. and Mestrovic, A. (2020). Structural Analysis of Factual, Conceptual, Procedural, and Metacognitive Knowledge in a Multidimensional Knowledge Network. Complexity, vol. 2020, Article ID 9407162, 17 pp.

[25] Vygotsky, L. S. (1986). Thought and language, Cambridge, MA: MIT Press. (Original work published 1934)