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Article

Anatomy of Educational Innovations Based on Learning by Discovery in Higher Education

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ABSTRACT

This study examines the teaching innovations resulting from the Bologna Process, focusing on problem-based learning and gamification, both of which emphasize the importance of autonomous learning. It reviews meta-analyses and prominent articles in the field of educational research from the last 5 years. Using a biomedical analogy, it identifies the active principles of discovery-based learning innovations, highlighting the subordination of theoretical content to practical skills and the disruption of the teacher-student dichotomy. Adverse effects are noted, such as the devaluation of lectures, the discrediting of teacher authority, and the infantilization of students. The effectiveness of discovery-based learning in higher education is considered weak and inconsistent, and caution is advised in its implementation, together with the preservation of the university's social function of transmitting knowledge at advanced levels.

Anatomía de las Innovaciones Docentes Basadas en el Aprendizaje por Descubrimiento en la Educación Superior

Palabras clave
Educación superior
Innovación pedagógica
Teoría carga cognitiva

RESUMEN

El objetivo de este trabajo es examinar las innovaciones docentes derivadas del Plan Bolonia, centrando la atención en el aprendizaje basado en problemas y la gamificación, que resaltan la importancia del aprendizaje por descubrimiento o autónomo. Se analizan metaanálisis y artículos prominentes en "Education" and "Educational Research" de los últimos 5 años. Utilizando un símil biomédico, se identifican los principios activos de las innovaciones basadas en aprendizaje por descubrimiento, destacando la subordinación de contenidos teóricos a competencias prácticas y la ruptura del binomio docente-estudiante. Se señalan efectos adversos como la devaluación de clases magistrales, desacreditación de la autoridad docente y la infantilización de estudiantes. Diferentes estudios indican que la eficacia del aprendizaje por descubrimiento en la educación superior es débil e inconsistente. Por tanto, se aboga por la prudencia en su implementación y la preservación de la función social universitaria para transmitir conocimiento a niveles superiores.

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The university is an institution of higher education aimed to prepare free citizens, who are able to understand and transform reality based on the acquired knowledge (Sant, 2019; UNESCO, 2005); the term "education"[1] implies an asymmetrical relationship between teachers and students according to their degree of knowledge and/or understanding of the discipline (Fernández-Liria et al., 2017); "higher" refers to the deepest or most abstract level of the contents of a discipline, which is organized hierarchically according to its internal logic (Aguadé, 2021; Rosenshine, 2012); and "free" implies the absence of coercion or interests outside academia that may hinder the critical analysis of reality and the interest in transforming it (Cranney & Dunn, 2011; Stglitz, 2003).

This social function of university higher education contrasts with the utilitarian value, usually promoted by economic institutions, focused on the training of entrepreneurial and/or employable workers for the market (Banco Mundial [World Bank], 1995; Fellnhofer, 2019; Powell & Snellman, 2004). The objective of the "Estrategia Universidad [University Strategy] 2015" (an initiative of the EU) was to "modernize" the Spanish university system, considering the aim of increasing its contribution to the economy (Ministerio de Educación [Ministry of Education], 2011). Within this utilitarian or economistic view, rigorous and critical professionals in a discipline may become a problem: "overqualification" (Carrera & Luque, 2016; Echegaray, 2018), i.e., "too many people with a lot of knowledge about unimportant things" (Lofton, 1972). It is counterintuitive, like the "excess of democracy" denounced by the economic institutions (Crozier et al., 1975; Dolgon, 2017).

In this context, the Organization for Economic Cooperation and Development (OECD) proposed reforms to reduce quality: "If the costs of schools or universities are reduced, the *quantity* should not be reduced, even though the *quality* of the service may suffer. [...] Families will react badly if their children are not admitted, but not if the quality of the education they receive is gradually reduced" (Morrisson, 1996, pp. 28). Only three years later, the Bologna Plan was initiated for the implementation of university reforms in the countries of the European Higher Education Area, which has resulted in the progressive precariousness of university higher education (Ferreiro, 2010; Galcerán, 2010). The university is redefined as a business and higher education as a consumer product (Aguadé, 2021; Fernández-Liria et al., 2017; Huguet, 2013; Laval, 2004; Martínez & Tarrès, 2013; Noll, 2019; Sandel, 2021; Soler, 2005). Therefore, the boom in teaching innovations—particularly those based on self-discovery, such as problem-based learning (PBL) or gamification—has emerged, with the declared intention of "improving" the quality of university teaching (Hmelo-Silver, 2004; van Grieken, 2014; van Alten et al., 2019). However, the rapid and extensive implementation of these innovations has resulted in radical changes in university teaching, as well as in teacher training and evaluation. Beyond their stated intentions, these innovations have not been critically analyzed on the basis of their effective impact.

The aim of this study is to examine the characteristics and effectiveness of innovations based on discovery learning, taking into account the available evidence in the context of university higher education. Special attention is given to problem-based learning (PBL) and gamification.

1 Translator's note: the term "enseñanza" was used in the original Spanish text, meaning "teaching".

Methodology

According to the bibliometric study by Ivanović and Ho (2019), a narrative review of the most cited meta-analyses from the last 5 years was conducted in the top journals in the field of educational research, The search was completed in the Web of Science (database), and the search keywords were "teaching innovation," "learning by discovery," "project-based learning," "problem-based learning," and "gamification." The meta-analyses were selected following the guidelines proposed by Pigott and Polanin (2020), excluding articles that were not directly related to teaching innovations or that were not applicable to university education.

In order to simplify the presentation of the results, a biomedical simile was used, whereby the fundamental components of the teaching innovations constitute the "active principles of the treatment"; their impact on university higher education are the "effects of the treatment" on classes; and teachers and students are the "plasma" and "vital organs" of the university, respectively. The articles chosen for this review are highlighted with an asterisk in the reference list.

Results

Following the biomedical analogy, the fundamental components of the teaching innovations based on learning by self-discovery (active principles) consisted of: 1) a reduction in the concentration of theoretical content, of a logical and rational nature, in favor of an increase in the concentration of practical competencies, of an experiential and emotional nature, and 2) the rupture of the teacher-student binomial as the core pillar of university teaching. These characteristics and their impact on the central aspects of university higher education are developed below.

University Classes as the Blood Plasma of the University

Traditionally, the contents of university lessons have been theoretical. For example, understanding what an antibiotic is and how it works, what human rights are and why they are just, or what Velázquez's Meninas are and why they are considered a masterpiece. Such theoretical knowledge requires rational or abstract thinking because it is not immediately accessible through experience or (self-) discovery, in other words, it requires direct instruction and effort (Jerrim et al., 2019; Oliver et al., 2019).

However, teaching innovations focused on (self-) discovery prioritize the teaching of practical content or competencies, understood as skills that enable you to do something. For example, in PBL, the resolution of problems is the content itself (Bell, 2010; Hmelo-Silver, 2004). This change is key because practical content or competencies (e.g., the use of antigen testing) do not require theoretical knowledge. However, this knowledge, for example, theoretical knowledge of biology and chemistry, is necessary in order to understand what they are or why they work, providing the rigor and soundness expected in the university as an establishment of reference in higher education.

This devaluation of theoretical knowledge provides an ideal breeding ground for the proliferation of misinformation and fake news (Iyengar & Massey, 2018; Lazer et al., 2018; Merkley, 2020; Scheufele & Krause, 2019; West & Bergstrom, 2021; Wood &

Porter, 2019) and the rise of anti-intellectualism, where the quality of theoretical knowledge based on reason is confused with opinions based on personal experiences. In the words of Isaac Asimov, "My ignorance is as valid as your knowledge". Indeed, theoretical knowledge is constituted as the most effective vaccine against this problem (Lewandowsky & Oberauer, 2016; Van der Linden et al., 2017).

The Teacher and the Student as Vital Organs of the University

Traditionally, the teacher-student binomial has been the basis of university education. It is characterized by an asymmetric relationship between the teacher—responsible for teaching the theoretical or higher-level contents of a discipline—and the student, the target of the teaching with the right (and responsibility) to learn the knowledge of each discipline according to his/her possibilities and limitations (Aguadé, 2021; Duffy & Jonassen et al., 2013; Eun, 2019; National Academies of Sciences, Engineering and Medicine, 2018; Yilmaz et al., 2008).

However, pedagogical innovations based on discovery learning break with this teacher-student binomial. On the one hand, the role of the teacher is no longer the logical and orderly presentation of theoretical content, but rather to guide, accompany, or facilitate the student's (self)discovery or autonomous learning (Finkel, 2008). On the other hand, the role of the student also changes; he/she ceases to be the recipient of the teaching to become the protagonist (student-centered learning), responsible for "his/her" own learning (autonomous or by discovery).

Inevitably, the authority of the teacher as an expert in the discipline he/she teaches is questioned. It becomes necessary to "teach [the university professor] how to teach" (Amat, 2009; Gonsálvez, 2014). Moreover, the student is infantilized to some extent, by putting the emphasis on disguising university teaching as a game or source of entertainment in order to motivate them (gamification), leaving ignorance behind or mastering a discipline is no longer the main objective (Gordillo, 2020; Kincade, Cook & Goerdt, 2020; Pérez-Álvarez, 2012). Instead, "learn to learn" (Ruíz, 2020) or to "learn to be" (Delors, 1996) become the new rhetoric goals.

Evidence on the (In)Effectiveness of Teaching Innovations Based on Discovery Learning

Surprisingly, the efficacy of discovery learning has been strongly questioned for more than half a century (Ausubel, 1968; Hermann, 1969). According to Ausubel (1968),

> "Actual examination of the research literature allegedly supportive of learning by discovery reveals that valid evidence of this nature is virtually non-existent. It appears that the various enthusiasts of the discovery method have been supporting each other research-wise by taking in each other's laundry, so to speak, that is, by citing each other's opinions and assertions as evidence and by generalizing wildly from equivocal and even negative findings." (Ausubel, 1968, p. 497-498).

More recent studies highlight serious methodological limitations: (1) Evaluations of the effectiveness of PBL, in general, have less than one month's follow-up, so the alleged benefits can be confounded with the "novelty effect" (Chernikova et al., 2020; Garzón & Acevedo, 2019; Garzón et al., 2020). (2) PBL innovations are extremely heterogeneous and lack solid theoretical basis, so it is difficult to determine which elements are responsible for the effects found (Zainuddin et al., 2020). (3) The effects are not generalizable from one discipline to another (Garzón & Acevedo, 2019; Garzón et al., 2020; Strelan, Osborn & Palmer, 2020). (4) The most widespread success criterion has been student and/or teacher satisfaction, not the degree of understanding or knowledge in the discipline (Chen & Yang, 2019; Soderstrom & Bjork, 2015; Zainuddin et al., 2020). Indeed, gamification increases enthusiasm for the task, but it does not improve the understanding of theoretical knowledge (Bai et al., 2020; Dochy et al., 2003; van Alten et al., 2019). (5) It is not specified under which circumstances (e.g., teacher, student, or content characteristics) some innovations are relevant as opposed to others (Diamond, 2013; Jansen et al., 2019; Klassen & Kim, 2019; Li, Antonenko & Wang, 2019; Mishra, 2020; Rodríguez-Hernandez et al., 2020; Zimmerman, 1989).

Nevertheless, in 2019, Forbes magazine published an article entitled "New, Strong Evidence for Problem-Based Learning" (Nietzel, 2019). The piece is, however, based on the results of a "working paper" published exclusively for discussion without peer review (Bando et al., 2019). The study in question was funded by the Inter-American Development Bank and the National Bureau of Economic Research. It consisted of 10 field experiments conducted in four Latin American countries, on 17,000 third and fourth grade primary school students, with the objective of estimating the effect of PBL in mathematics and science. Paradoxically, the procedure for random assignment to the experimental and control conditions is not described, the control condition is not defined, and the three central elements of the experimental condition (PBA) included direct instruction. Specifically: 1) instruction of key concepts, 2) provision of "problem-solving opportunities" in class, and 3) use of students' prior knowledge, with structured scaffolding to help them develop increasingly complex activities. The effect sizes found at the one-year follow-up were small, generally below 0.1 standard deviation. In summary, the empirical results are inconsistent with Forbes' headline: "Strong new evidence for PBL", and in no way are they generalizable to higher education.

Learning by Self-Discovery Based on Cognitive Load Theory

According to the cognitive load theory (CLT), discovery learning is inconsistent with the available knowledge about basic teaching and learning processes (Bransford et al., 2000; Kincade, Cook & Goerdt, 2020; Mayer & Moreno, 2003; Renkl, 2014; Sweller, 2020). Randomized controlled studies demonstrate that effective learning requires understanding and connecting new knowledge to existing prior knowledge, and also the prior instruction that enables the presentation of new information in a coherent and logical manner (Diamond, 2013; Geary, 2008; Sweller et al., 2011; Sweller, 2020, 2021). There are several reasons:

First, we must distinguish between two types of knowledge: (1) generic knowledge (biologically relevant), such as the ability to solve problems, oral language, or social skills, which can be learned spontaneously, effortlessly, and without the need to be formally taught; and (2) specific knowledge (culturally relevant), such as written language or knowledge of each discipline, which requires

effort on the part of the student and direct instruction on the part of the teacher (Sweller, 2020; Sweller et al., 2019; Tricot & Sweller, 2014). In other words, theoretical knowledge specific to university higher education requires effort on the part of the student and direct instruction from the teacher.

Second, we must distinguish between two types of information processing: (1) the processing of new information that is limited in capacity (3-7 items) and duration (15-20 seconds) by our working memory (Chen et al., 2018; Cowan, 2001; Miller, 1956); (2) the processing of information previously consolidated in our long-term memory, with extended capacity or duration (Sweller et al., 2019; Sweller, 2020). In other words, discovery-based learning is the way of processing new information when we have no prior knowledge in our memory or direct instruction. Essentially, it represents classic trial-and-error learning (Chen et al., 2017; 2018; Garnett, 2020; Kirschner et al., 2006; Sweller, 2020; 2021; Sweller, van Merriënboer & Paas, 2019).

Third, the difference between experts and novices in any discipline lies precisely in the prior knowledge stored in long-term memory (De Groot, 1965; Dunlosky et al., 2012; Sweller, 2021). Therefore, discovery or problem-based learning only makes sense once the level of knowledge is high enough to make explicit presentation of content or direct instruction redundant (also known as the expertise reversal effect) (Chen et al., 2017; Clark, Kirschner & Sweller, 2012; Sweller, 2021).

Fourth, from an evolutionary standpoint, language—on which lecturing or direct instruction is based—is the most efficient form of teaching (Jerrim et al., 2019; National Academies of Sciences, Engineering, and Medicine, 2018; Oliver et al., 2019), as it reduces the working memory load associated with autonomous or discovery learning (Chen & Yang, 2019; Kirschner et al., 2006; Renkl et al., 2009).

Fifth, learning is not constructed autonomously but rather socially, which underscores the importance of help from others who know more and are willing to teach (Rosenshine, 2012; Tobias & Duffy, 2009). Indeed, direct instruction allows us to provide scaffolding based on the student's prior knowledge (Ausubel, 1968), reducing or eliminating the overload of irrelevant or redundant information in solving a problem (Clark et al., 2006; Van Merrienboer et al., 2003).

Sixth, according to CBT, a teacher's effectiveness in teaching is inseparable from their expertise in the area of knowledge, because it allows them to clearly organize and explain the contents of the discipline (Moradiellos, 2003; Rosenshine, 2012; Strelan et al., 2020; Sweller, 2021; Sweller et al., 1990). Precisely, the problems of transferring learning to other contexts require the teacher to augment or make explicit, through direct instruction, the useful information needed to recognize previously learned content in a new situation (Boshuizen et al., 2020; Clark et al., 2006). However, PBL underestimates the problem of knowledge transfer (Aksayli et al., 2019; Boshuizen et al., 2020; Garnett, 2020).

In summary "*Somehow, during the history of educational thought, we decided that problem solving was a good way of learning without any evidence. It is a terrible way of learning. We decided that problem solving was a good way of learning without even attempting to obtain evidence from randomized controlled experiments. Problem solving is a poor way of learning because it imposes a large cognitive load (*Sweller, 2015, p. 131*)*

Indeed, expecting students to discover knowledge on their own or with minimal instruction, rather than teaching them directly makes no sense, and is not based on empirical evidence but on dogma (Clark et al., 2006). Direct instruction and the development of examples are necessary, however, especially for novices (Alfieri et al., 2011).

Improvement of University Teaching Based on Evidence

The following proposals should be considered to improve the quality of university higher education:

1. As a starting point, it must be assumed that teaching "something" requires "knowing" something. Therefore, the efficacy of teaching will necessarily depend on the teacher's knowledge and ability to clearly organize and explain the contents of the subject, adapting it to the level of the students. In other words, the methodological aspect, *how to* teach, must be subordinated to the disciplinary aspect, *what to* teach, *by whom*, and *to whom*.
2. The social function of higher education in the formation of free and critical citizens must be guaranteed, bringing us closer to truth through the sciences, and to justice and beauty through the humanities and arts respectively (Aguadé, 2021; Boyack et al., 2005; Carbonell, 2017; Fernández-Liria et al., 2017). The prioritization of practical skills responds to non-academic employability/profitability criteria (OCDE, 1997). The "entrepreneurial spirit" or "the ability to be flexible and to self-regulate emotionally in situations of uncertainty" facilitates the adaptation to a precarious labor market, but not in order to understand or transform it (Fellnhofer, 2019; Powell & Snellman, 2004).
3. Teaching innovations should satisfy the prudence criterion "*Primum non nocere*" or "first do no harm", especially if they imply radical changes in the function of the university, its organization through the teacher-student binomial, or the role of lectures. Extraordinary claims require extraordinary evidence (Tressoldi, 2011), and as far as we are aware, teaching innovations based on discovery learning such as PBL or gamification have not improved the quality of university higher education (Stéphan et al., 2019) and they are inconsistent with the evidence provided by CBT (Delgado et al., 2018; Sweller, 2021; Zhang et al., 2022).
4. The "commoditization" of university higher education must be reversed; it has been turning faculty evaluation into another incentive to increase productivity (Fernández-Liria et al., 2017; Indocentia, 2016), an instrument of control and/or bureaucratization of teaching activity (Aguadé, 2021; Fernández-Liria et al., 2017; Martínez-Gorriarán, 2017; Villarreal, 2017), radically modifying "what" and "how" one teaches (Ferreiro, 2010; Galcerán, 2010; Laval, 2004; Soler, 2005). Similarly, the incentives of scientific research have modified (i.e., "what" and "how" research is conducted), generating an inflation or accumulation of articles that are superficial or of poorer methodological quality (Callaway, 2016; Editorial, 2019; Guides, 2010; Mayer, 2004; Nuzzo, 2015; Sanjana, 2021; Wilsdon et al., 2015). Teaching excellence implies rigorous adaptation to the epistemological demands of the scientific discipline in question. Thus, it can

only be evaluated by experts in the same discipline, not by the satisfaction of customers/users or the standardization of the service/product, nor by "experts" outside the discipline to be evaluated, as is currently the case in faculty evaluations (ANECA, 2019).

5. The precariousness of the teaching staff must be reversed, guaranteeing teaching by teachers who are experts in their area of knowledge (Abad-Ramón, 2021; Aunión, 2020; García, 2020; Sánchez-Caballero, 2020; Yslado-Méndez et al., 2021), academic freedom versus economic/market interests (Powell & Snellman, 2004; Sirin, 2005), and not instrumentalizing teaching as a punishment to enhance research performance.
6. The devaluation of lectures must be avoided, as well as the role of memory as a pretext for implementing arbitrary teaching innovations inconsistent with available scientific knowledge. Innovation seems to have become an end in itself, and something that is positive *per se.* For example, PBL itself continues to be presented as an innovation, despite having been proposed more than a century ago (Kilpatrick, 1918). Most teaching innovations emphasize the need to incorporate new technologies into university higher education contrary to much of the available empirical evidence (Anger & Alexander, 2017; Aragón-Mendizábal et al., 2016; Jeong & Gweon, 2021; Skowronek et al., 2023).

Conclusions

The objective of this study was to analyze the characteristics and effectiveness of teaching innovations based on discovery learning in the context of university higher education. Following a biomedical analogy, the two fundamental elements (active principles) of teaching innovations based on discovery learning are: (1) the devaluation of theoretical content in favor of practical skills demanded by the market, which is consistent with the rise of anti-intellectualism; (2) the rupture of the teacher-student binomial making the student both responsible for and the target of university teaching, which discredits the authority of the teacher, as the person responsible for teaching, assigning them a peripheral role and non-academic functions as their main role (i.e., accompanying or motivating). In addition, the effectiveness of teaching innovations focused on discovery learning is inconsistent with the results of randomized controlled studies, which emphasize direct instruction (e.g., lectures), as the most efficient way to deal with new and/or complex information in higher education. Finally, having identified the potential adverse effects of these teaching innovations, and in light of the available scientific evidence on their (in)efficacy, it is recommended that the precautionary principle (Article 191 of the Treaty on the Functioning of the European Union) be taken into account when making decisions on the implementation of these innovations. In particular, they involve radical changes which should be supported by solid scientific evidence that demonstrates their benefits and/or determines the associated implementation risks with sufficient certainty for each case. The responsibility for demonstrating the benefits and/or absence of risks should lie with the proponent of these teaching innovations, not the recipient.

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Conflict of Interest

Authors declare no conflict of interest.

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