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# TRANSDUCTION IN EDUCATION: BIBLIOMETRIC STUDY OF TRENDS IN THE APPLICATION OF THE CONCEPT IN TEACHING AND LEARNING

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## Abstract

*The concept of transduction, originally developed in biology and engineering to describe processes of transformation between different forms of energy, matter, or information, has progressively gained relevance in educational research. This article presents the results of a bibliometric study aimed at analyzing trends in the use of the concept of transduction within the contexts of teaching and learning. Using the Scopus database, a search equation (TITLE-ABS-KEY ("transduct*" AND "teaching" AND "learning")) was applied, identifying 89 research products published between 1998 and 2024. Bibliometric analyses of co-authorship and keyword co-occurrence were conducted using VOSviewer software to examine thematic relationships, temporal trends, and international collaboration patterns. The results reveal a growing interest in the topic, particularly from 2017 onward, with the highest production concentrated in the United States and the United Kingdom. Although the concept remains predominantly associated with neuroscience, biochemistry, and computer science, its presence in the social sciences indicates an emerging educational perspective. Co-occurrence analysis*

***highlights recent connections with curriculum, psychology, students, and training, while signal transduction and learning remain central nodes. The discussion emphasizes the theoretical grounding of transduction within General Systems Theory and its pedagogical implications, particularly in science and engineering education. Empirical studies show that transduction facilitates the transformation of meanings across multiple semiotic modes—such as diagrams, simulations, physical devices, and multimodal representations—enhancing conceptual understanding and supporting inclusive and equitable learning environments. The article also proposes that integrative projects in engineering programs can be understood as transductive devices that enable the transfer and transformation of knowledge across disciplinary domains. The findings suggest that transduction constitutes an emerging and promising framework for educational research and practice, warranting further exploration to strengthen interdisciplinary integration, multimodal learning, and the development of complex problem-solving competencies.***

**KEYWORDS:** Transduction, Education, Teaching, Learning.

# 1. INTRODUCTION

By transducer, it is originally understood as "a device that receives energy of a certain nature and subsequently supplies another of a different nature, but depending on the initial energy" (Nise, 2011). Another author states that "a transducer is a mechanism that receives energy from one system and retransmits it, often in another form, to another system." (Rumelhart, 1983). As for the reasoning processes, it is associative rather than implicative and causal. The International Encyclopedia of Systems and Cybernetics (François, 2004) defines it as "some device or system that carries matter, energy, or information from one system or subsystem to another, from or to the environment.

On the other hand, J. Miller defines three types of transducers: input, internal, and output, all related to information processing. For the transport of matter and energy, he uses other descriptions: ingestor, converter and extruder..." And he adds: "A computer program is a transducer of knowledge. Similar to any energy transducer; A computer program has an input of knowledge and an output of knowledge." The same text defines the function of a transducer as "Transduction: any transformation or encoding process that modifies an input or output. Transduction is generally necessary in order to harmonize the interrelationships between a system and its environment, or between subsystems and the system to which they belong." (François, 2004). A transducer is, in short, an agent that transmits, that carries, through a certain medium some type of information, energy or object that, when transmitted, would undergo some kind of transformation.

Within the framework of the above proposal and the implications of what would eventually be called a "transducer device", Samaja (2012) presents how the "need for a transduction function between description and tautology" is made explicit. In this sense, it is necessary to consider the relevance of this concept in the educational field; The reflection on the existence of such an element is intended to the extent of the consolidation of a methodological and intermediary strategy of the processes associated with the tensions always present in the teaching work, which in this case, will be analyzed from teaching and learning.

In line with the above, this article presents the results obtained from a bibliometric study regarding the use of the concept of transduction in the fields of teaching and learning. To this end, the search for related articles in Scopus databases is proposed, generating an analysis of the way in which it interacts or relates to other concepts.

# 2. METHODOLOGY

The methodological development of the research was carried out through the use of bibliometric components considering co-authorship analysis and co-occurrence analysis through the use of the free software VOSViewer (Van Elk & Waltman, 2007) as proposed in Surwase et al. (2011).

Through the generation of a search equation on the Scopus platform, articles that work on the concepts of transduction, teaching and learning were identified. In this sense, the following search equation was applied:

TITLE-ABS-KEY ( "transduct*" AND "teaching" AND "learning" )

Equation 1. Boolean terms in search

Based on the above equation, it is specified that the search is carried out for articles that contain in their abstract, title or keywords, the concepts of transducer, transducer, teaching and learning. From the articles obtained and the analyses of their contents, a general overview and analysis of trends of the concept of transduction in the educational field is obtained.

# 3. RESULTS

By applying the search equation in Scopus, 89 research products were obtained in the period between 1998 and 2024, with different interannual variability of behavior, as can be seen in Figure 1.

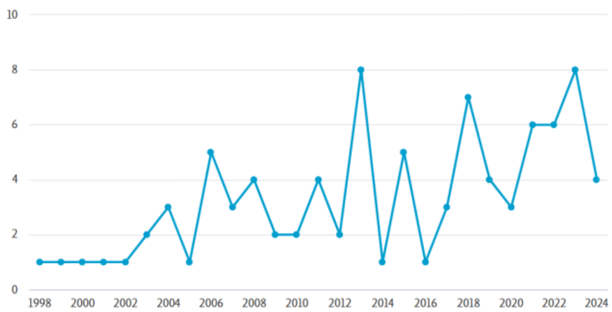


***Figure 1: Output of articles according to the applied search equation.***

A trend towards a maximum value of 8 articles can be observed, with which it can be identified that the concept is not yet fully explored, but that it has increased its levels of interest since the period 2017 – 2024, while 3 or more annual publications are presented. In relation to publications by country, the results can be seen in Figure 2.

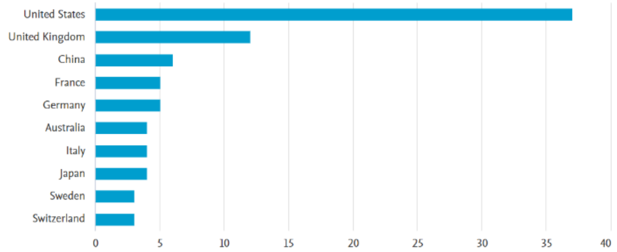


*Figure 2: Production ratio by country.*

It can be seen that the country with the highest production is the United States, totaling 37 documents in Scopus, followed by the United Kingdom with 12 and China with 6. In the Latin American region, the country with the highest production is Argentina with 2 articles related to biochemical components (Blanco & Blanco, 2017) and the understanding of intellectual disability through digital devices. Regarding the related areas of knowledge, the results can be identified in Figure 3.

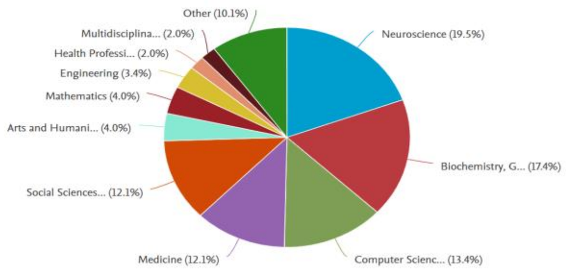


*Figure 3: List of areas of knowledge.*

It is observed that the area of knowledge with the highest production is neuroscience with 19.5%, followed by biochemistry (17.4%) and computer sciences with 13.4%. It is necessary to consider that the social sciences present a production of 12.1%, which indicates that there is not much production in this regard, and the concept can be considered as "emerging" in this area. When doing the bibliometric analysis, the following results are obtained.

Regarding the co-authorship analysis, the relationship of the references obtained was considered according to the number of documents co-authored by country, obtaining as a result what is presented in Figure 4.

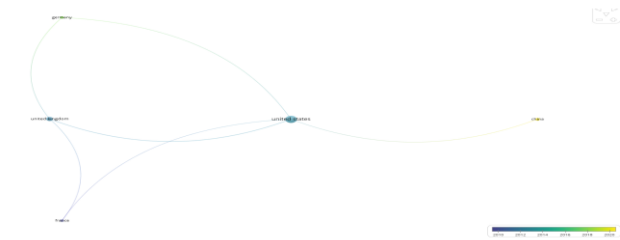

*Figure 4: Visualization of co-authored data overlay by countries in time ranges.*

Figure 4 shows the existence of co-authored relationships in Germany, the United States, the United Kingdom, China and France, where the most recent relationships are between Germany, the United States and China. In relation to the co-occurrence analysis, the relationships in Figure 5 are identified.

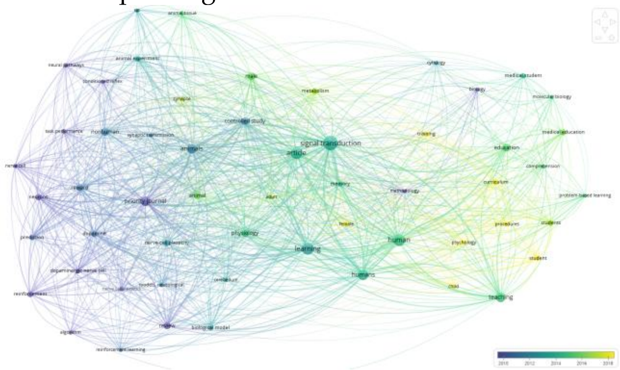

*Figure 5: Visualization of co-occurrence relationships in terms of temporal data overlap.*

The results obtained show how the most recent concepts associated with the articles are related to the words curriculum, procedures, students, psychology and training. Regarding the keywords with the most interrelationships, signal transduction, learning, human and teaching are identified.

## 4. ANALYSIS AND DISCUSSION

It is relevant to consider that the concept of transduction is originally conceived from biology and engineering but that this concept has recently been transformed in the field of education through the options proposed in the concept of isomorphism proposed within the framework of the General Systems Theory since, as Carnicer (2012) mentions:

the General Systems Theory proposes theoretical models that can also explain, predict and control human phenomena. Due to its transdisciplinary nature and its interdisciplinary applications, we can affirm that it transcends the ordinary compartments of science, promoting isomorphism between models, principles and laws. Psychologists, teachers and educators, as mediators, should not give up some of the practical applications that TGS brings to the human and behavioral sciences. (p. 1)

Limiting the area in which the research is limited to social sciences, 18 documents are identified, of which 5 specifically present the concept of transduction in the field of teaching and learning, which connect directly with the contributions of the General Systems Theory to the connection of the concept of transduction in education and that make room for the concept of transducer device. Transduction, defined as the process of transferring meanings from one semiotic system to another, plays a relevant and understudied role in education and learning. This process allows students to translate information between different formats, promoting a deeper and more holistic understanding. General Systems Theory (GST), developed by Ludwig Von Bertalanffy, presents an interdisciplinary approach that studies complex systems and their interactions. In the educational context, a system may include elements such as students, teachers, teaching resources, infrastructure, and the interactions between these components (Bertalanffy, 1968).

Under this framework, Volkwyn, Airey, Gregorcic, and Heijkenskjöld (2019) explore the use of transduction in physics teaching in secondary school laboratories, describing how physics devices, such as the IOLab, facilitate transduction by converting invisible magnetic fields into visual representations understandable to students. Transduction allows students to interpret and understand complex physical phenomena through multiple semiotic modalities, improving both conceptual understanding and assessment by teachers (Volkwyn et al., 2019).

Tytler and Prain (2022) examine transduction in the context of astronomy teaching in elementary school, highlighting how teachers can guide students in the creation and linking of meanings through different representational modes, which is essential for the learning of concepts and processes in science. Research shows that transduction facilitates the alignment and expansion of meanings through multimodal representations (Tytler & Prain, 2022). On the other hand, Skyer (2023) investigates multimodal transduction in pedagogy for deaf people, pointing out how deaf teachers use transduction to convert inaccessible modes into accessible ones for deaf students. This process improves understanding and enhances equity in education, demonstrating the importance of transduction in deaf education for both teaching and learning (Skyer, 2023).

In a perspective oriented towards the learning of scientific concepts, Madsen (2013) presents a study on how the transformation of these through drawings and speeches in the classroom allows students to better understand scientific content. This process of transduction, which involves reading, image creation and oral presentation, in addition to facilitating individual comprehension, promotes collaboration and communication in working groups. Drawings act as mediators in learning, helping students to translate and consolidate their knowledge through multiple representational modes (Madsen, 2013). In this same context, in the study by Xu et al. (2023), we investigate how students use transduction to link and transform meanings through different representations in science learning. Research suggests that students need guidance from the teacher to navigate these transductions, highlighting the importance of the teacher's role in facilitating and overseeing this process. Teachers can use strategies such as the introduction of persistent semiotic resources and coordination centers to help students construct and consolidate coherent scientific meanings (Xu et al., 2023).

To plan effective lessons that use transduction, teachers must consider the set of resources necessary for disciplinary meaning-making. It is important to balance the amount and type of resources to avoid cognitive overload and ensure that resources are persistent when needed. During teaching, teachers should be attentive to students' use of semiotic resources and ensure that these are used in a manner consistent with disciplinary meanings (Xu et al., 2023).

### *Contributions to Engineering Education*

In engineering programs, semiotic resources and transduction facilitate students' learning of complex concepts and understanding. Diagrams, graphs, and visual models are essential tools in engineering that help students visualize complex structures, systems, and processes. For example, in civil engineering, workflow diagrams, architectural plans, and 3D models of buildings allow students to better understand structural and design concepts (Volkwyn et al., 2019). It is equally pertinent to consider how computer simulations and software tools, such as MATLAB, AutoCAD, and SolidWorks, enable students to interact with digital models of systems and processes. These tools facilitate transduction by allowing students to see how changes in variables affect systems in real time. For example, in electrical engineering, circuit simulators allow students to experiment with different circuit configurations without the need for physical hardware (Tytler & Prain, 2022).

Using multimedia presentations that integrate text, images, videos, and animations can help students understand engineering concepts from multiple perspectives. For example, in mechanical engineering, a lesson on how an engine works may include a video showing the engine in operation, diagrams that break down its components, and a verbal explanation of the process (Madsen, 2013). Engineering labs are spaces where students can apply theories and concepts in a hands-on environment. Here, tangible semiotic resources, such as electronic components, building materials, and testing equipment, are used to reinforce learning. These labs allow students to translate theoretical knowledge into practical skills, thus facilitating the transduction of abstract concepts into concrete experiences (Skyer, 2023).

As an additional aspect, it is considered relevant to conceive the mastery of technical language. In that sense, engineering students must learn to translate complex concepts into precise and clear technical terms. This includes the ability to read and write white papers, create specifications, and communicate effectively with colleagues and industry professionals (Xu et al., 2023). The integration of systems and concepts from various disciplines is common in engineering. Transduction makes it easier to understand how these different systems interact. For example, an environmental engineering project may require knowledge of biology, chemistry, and environmental science, and students must be able to translate and apply knowledge from these various areas to solve complex problems (Volkwyn et al., 2019).

An interesting approach to the application of transduction in the curricular processes of engineering training programs can be verified in García-Arango (2014). This article presents how integrative projects in engineering programs typically require the combination of knowledge and skills from various disciplines. This interdisciplinary and eventually transdisciplinary approach is a key aspect of transduction, as it involves the transfer and transformation of meanings between different semiotic systems. For example, a project that combines civil, environmental, and electrical engineering needs students to translate concepts and data between technical diagrams, mathematical models, environmental impact analysis, and other modes of representation (Tytler & Prain, 2022). Integrative projects typically involve a variety of semiotic resources, students must use technical language to write reports, create diagrams and visual models to represent structures and systems, and employ simulations and software to perform tests and analyses. These semiotic resources allow the transduction of theoretical knowledge into practical applications and vice versa. According to Volkwyn et al. (2019), the utilization of simulation tools and modeling software facilitates the understanding of complex concepts by allowing students to see how systems behave in different scenarios.

In line with the above, integrative projects encourage the development of communication and collaboration skills. Students must present their results clearly and effectively, which involves translating complex technical concepts into presentations that are accessible to different audiences. This may include creating multimedia presentations, using graphs and diagrams, and verbally explaining your findings. Madsen (2013) highlights that the use of multiple modes of representation in teaching improves the comprehension and retention of information. Table 1 presents a first approach to the development phases of an integrative project, the associated semiotic resources and their contribution to training in engineering programs.

***Table 1: Relationship between the Phases of an Integrative Project, Semiotic Components and Contribution to Engineering Training.***

| Integrative Project Phase | Semiotic Components | Contribution to Engineering Training |
|---|---|---|
| *1. Problem Definition* | Technical language (writing, discussions) | Development of communication skills and precision in technical language |
| | Flowcharts | Clarification and structuring of the problem |
| | Concept maps | Promotion of critical and analytical thinking |
| *2. Research and Data Collection* | Academic texts | Improved research and data analysis skills |
| | Databases | Interpretation of complex information |
| | Questionnaires and surveys | Integration of theoretical and practical knowledge |
| *3. Design and Planning* | Technical drawings and diagrams | Application of design and engineering knowledge |
| | 3D models and simulations | Use of advanced technological tools |
| | Design Software (AutoCAD, SolidWorks) | Development of planning and organizational skills |
| *4. Implementation and Development* | Physical prototypes | Moving from theoretical design to practice |
| | Computer simulations | Evaluation and adjustment of technical solutions |
| | Instruction manuals and technical guides | Strengthening practical and technical skills |
| *5. Evaluation and Testing* | Test Reports | Technical solution validation |
| | Analysis of results (graphs, tables) | Identification of areas for improvement |
| | Feedback and Reviews | Application of rigorous evaluation methods |
| *6. Presentation and Documentation* | Oral and multimedia presentations | Improved presentation and communication skills |
| | White Papers | Ability to synthesize and communicate results |
| | Data visualizations (infographics, charts) | Preparing for the dissemination of findings and solutions in professional contexts |

The table presented shows how different phases of an integrative project in engineering programs can be seen as transducer devices that use various semiotic resources. Each phase, from the definition of the problem to the presentation and documentation, incorporates tools and means that facilitate the translation of theoretical concepts into practical applications and vice versa. When defining the problem, flowcharts and concept maps are used to help clarify and structure the task to be addressed, developing critical and analytical skills in students. During research and data collection, academic and graphic texts facilitate the integration of theoretical and practical knowledge. The design and planning phase benefits from technical drawings and 3D models that allow the application of design knowledge and the use of advanced technological tools. In implementation and development, physical prototypes and digital simulations translate theoretical design into practice, strengthening students' technical skills. Evaluation and testing, through reports and analysis of results, validate technical solutions and apply rigorous evaluation methods. Finally, presentation and documentation using multimedia presentations and technical reports improve communication skills and the ability to synthesize and publicize results.

## 5. CONCLUSIONS

Transduction is a process of interest in the educational field, it facilitates the understanding and communication of complex concepts through multiple representational modes. In the bibliometric study, applied research in science teaching, pedagogy for deaf people and the use of drawings in the classroom were identified, demonstrating their effectiveness. Teachers play a great role in guiding and supporting students in this process, ensuring that meanings are coherent and that learning is accessible and equitable. The research highlights the need to continue exploring the pedagogical possibilities of transduction to improve education in various contexts.

Integrative projects can be seen as transducer devices that use semiotic resources to facilitate the transfer and transformation of knowledge between different domains and modalities. By combining disciplines and employing a variety of semiotic resources, these projects not only improve the understanding and application of technical concepts, but also prepare students to face complex problems in their future professional careers.

The integration of transduction and semiotic resources in engineering education, through integrative projects, offers a little-explored approach with a potential impact on improving the understanding and application of complex concepts. By viewing integrative projects as transducer devices, one can opt for the transfer of knowledge and skills between various disciplines and modes of representation, this methodology not only enriches theoretical and practical learning, but also develops key competencies such as technical communication, critical thinking, problem-solving skills and interdisciplinary collaboration. Ultimately, this approach could imply a greater contribution to students not only of engineering but of other professions to face real challenges in their future careers, giving rise to them being able to apply their knowledge effectively and adaptively in an increasingly complex and connected world.

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