

## **Regenerative Medicine in the Secondary Education Curriculum in Spain: Literacy in a New Medical Paradigm**

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### **Abstract**

*This study investigated the presence of basic content related to regenerative medicine in secondary education textbooks in Spain as an approach to determining student literacy in this new paradigm of medicine. We identified ten concepts related to regenerative medicine, and carried out a quantitative evaluation of 12 textbooks. The fundamentals of cell and tissue structure were mentioned in 1% or more of the lines of text, and some items showed a significant correlation throughout secondary education. The items extracellular matrix, cell differentiation, cell death, cell-cell contact, growth factors, cell culture, cell therapy, and tissue engineering were present in less than 1%. Although the items stem cells and growth factors, basic concepts in regenerative medicine, were present in the textbooks analyzed here, the absence of the item biomaterials can potentially hinder the acquisition of appropriate literacy in this new paradigm, and hence the quality of health education, during secondary education.*

**Key words:** Paradigm, literacy, regenerative medicine, curriculum, secondary education

### **1. Introduction**

Secondary education is one of the fundamental pillars in the education of the citizens of any country. Accordingly, this stage of education should regularly incorporate new ideas, concepts, and information that give rise to the main paradigms that students will encounter in their daily life and social development, in order to equip them to understand the world and take part in day-to-day life. The incorporation of the theory of evolution and ecological sciences into the secondary school curriculum are obvious examples of the importance of keeping secondary education up to date. In the area of medicine and health, scientific research has in recent years become a rich source of knowledge that is changing the classical paradigms of medicine, generating along the way important social, economic, and cultural changes. As a consequence, new models of health education have arisen (Passamani, 2013). Among the most notable of these advances is the development of the human genome, of new technologies with health applications, and the birth of regenerative medicine. In connection with this last biomedical paradigm -the most recent to make its appearance- its impact has been so remarkable that it is generating new approaches to medical care with curative intent. Since the dawn of humanity, words, physics, chemistry and surgery have been used in efforts to cure; in recent decades it has been shown that cells and tissues are also able to cure (Salgado et al., 2013).

Although secondary schooling has traditionally included content linked to the human body and health within the area of Biology teaching, the incorporation of curricular material related with medicine, and thus with ways of understanding medicine, has been slow despite the fact that knowledge of illness and health is essential for individuals to become active participants in society. Acquiring health literacy, as several authors have shown, constitutes a fundamental process in the development of appropriate health education (Baker, 2006; Evans, Lewis, & Hudson, 2012; Zarcadoolas, Pleasant, & Greer, 2005).

In this study, our aim was to identify and quantify the inclusion of content related with the regenerative medicine paradigm in officially-approved textbooks used in the system of compulsory and elective pre-university secondary education currently in effect in Spain. Ultimately, we wished to know whether the textbooks now available to students and teachers contain the basic conceptual information needed for members of society to understand and use regenerative medicine concepts.

In the Spanish educational system, compulsory secondary education (CSE) aims to prepare students between the ages of 12 and 16 years for further education or for the labor market, while elective pre-university education (Baccalaureate (*bachillerato*), abbreviated here as PREUB) comprises 2 additional years that students between the ages of 16 and 18 years can enroll for voluntarily once they have completed the four years of CSE. Successful completion of the 2-year PREUB curriculum is a requirement for university enrollment. The quantitative research model used for this research on textbook content has been used previously via different approaches in different areas of science, and is a useful procedure for identifying the presence of content specific to a particular scientific paradigm. The model is also useful for research designed to study levels of literacy that students attain in specific science-related themes (BouJaoude, 2002; Chiappetta, & Fillman, 2007; Chiappetta, Fillman, & Sethna, 1991; Chiappetta, Sethna, & Fillman, 1991, 1993; Wilkinson, 1999).

## **2. Methods**

### **2.1 Procedure and instrumentation**

For this study our first step was to identify, basic content items we felt are needed to ensure an adequate knowledge and understanding of regenerative medicine, particularly regarding the use of artificial cells and tissues. Our method, based on the criteria established by Shulman (1987) and known as pedagogical content knowledge consisted of determining knowledge content elements that can be taught. To identify specific knowledge content items of relevance, we consulted the contents of the book *Tissue Engineering* by Palsson y Bhatia (2004), a well-known, now-classic source widely used in the teaching of regenerative medicine.

The ten content themes we identified as elements of pedagogical content knowledge, and the specific items in each theme, were 1) tissue organization: cell, extracellular matrix and tissues; 2) tissue dynamics, i.e. tissue renovation, 3) morphogenesis: induction and embryological development; 4) stem cells; 5) mechanisms involved in cell fate, including cell differentiation, cell migration, cell division and cell death; 6) mechanisms of cellular coordination including growth factors, cell-matrix interaction and cell-cell interaction; 7) cell culture techniques; 8) biomaterials; 9) cell therapy and tissue engineering; and 10) host integration of artificial tissues. The presence of these content themes and their related items was studied in 12 natural sciences textbooks used in the four grades of CSE and the two grades of PREUB. Six are published by Anaya (LT1) and six by Editorial Bruño (LT2), and all were officially approved for the academic year 2011-2012 in Spain.

### **2.2 Data analysis**

To obtain quantitative data we counted the number of lines of text in each textbook that contained any of the content themes or items on our list. In addition, we counted the number of pages in each textbook that covered material in the area of Biology. For statistical analysis, we used Pearson's correlation coefficient to identify relationships between the frequency of specific content items and the academic grade the textbooks were used for. This correlation was considered statistically significant when the value of  $r$  was 0.70 or higher.

## **3. Results**

The quantitative data for the number of lines of text mentioning Biology, including themes and items relevant to the area of regenerative medicine are summarized in Table 1. The percentage of text lines with the content of interest ranged from 18.99% and 32.16% in textbooks used for CSE grade 1 to 79.0% and 93.22% in textbooks used for PREUB grade 2. Figure 1 shows the percentage frequencies of lines of text with Biology-related content in textbooks used for each of the six grades of secondary education.

For textbooks published by both publishers, the frequency showed a statistically significant correlation with advancing grade of education ( $r=0.81$  for LT1,  $r=0.87$  for LT2). For each textbook analyzed here, we classified the percentage of text lines that mentioned Biology-related themes and items relevant to regenerative medicine as equal to or greater than 1%, and less than 1%. Table 2 and Figures 2 and 3 show the results for frequencies  $\geq 1\%$  across the 12 textbooks for CSE and PREUB, and Table 3 and Figures 4 and 5 present the results for frequencies  $< 1\%$ . In textbooks from both publishers, the items cell and cell division showed a statistically significant correlation with advancing secondary education grade ( $r=0.85$  for LT1,  $r=0.70$  for LT2). The items induction, tissue dynamics, cell migration, cell-matrix interaction, host integration of new tissues, and biomaterials were not present in any of the textbooks from either publisher used for any of the four grades of CSE or the two grades of PREUB.

#### **4. Discussion**

The incorporation of concepts and paradigms related with medicine into the secondary education curriculum has generally been infrequent despite the consequences of illness and disease for individuals and for society, and despite the importance of health literacy for making informed choices, reducing health risks, and increasing quality of life (Zarcadoolas, Pleasant, & Greer, 2005). The research reported here used a quantitative approach to investigate the presence of the new regenerative medicine paradigm in the compulsory (CSE) and elective stages (PREUB) of the Spanish secondary education system.

Our study focused on the most widely used and officially approved natural sciences textbooks in these two stages of secondary education in Spain. Although literacy in regenerative medicine and medical sciences has been tested with a proven method, i.e. audiovisual teaching media (Campos-Sánchez et al., 2014; Wilson, González, & Pollock, 2012), textbooks are, along with the teacher, the main vehicle of knowledge transmission, particularly in the Spanish educational system, where textbooks for each subject are officially approved by regional government education authorities. Nevertheless, it should not be overlooked that the overall focus of some textbooks has been the subject of some criticism. For example, it has been claimed that some textbooks present science as a set of answers rather than an exploration of questions and issues, and some have noted that science is presented in some textbooks as a body of information rather than an approach to understanding information within different contexts (Glynn, Yeany, & Britton, 1991; So, Tang, & Ng, 2000). It is, however, beyond the scope of the present study, focused as it is on textbook content, to attempt to discuss the pedagogical orientation of the different textbooks we compared here.

For our analysis we first counted the number of lines of text that contained material related to Biology, a knowledge area included in the natural science textbooks that we compared, and which covers scientific knowledge related with health and disease. Our results document a statistically significant correlation between the number of lines of text dealing with Biology and increasing grade level in both stages of secondary education. This correlation increased fourfold for Biology-related content in textbooks for the fourth and final year of CSE compared to those for the first year of CSE, and almost threefold in textbooks for the second year of PREUB compared to those used for the first year of PREUB. Regardless of the difficulties implicit in Biology teaching and current teaching methods (Tanner, Chatman, & Allen, 2003), we found that Biology-related textbook content was an increasingly relevant and important element of education in scientific culture from one grade to the next in the Spanish secondary school curriculum.

Our choice of content items related with regenerative medicine was based on the well-known manual by Palsson and Bhatia (2004). These items constitute an indispensable corpus of basic knowledge for understanding the concept and significance of regenerative medicine and according to the criteria of Shulman (1987) and van Driel et al., (1998) constitute information that can be implemented for teaching purposes. To compare the presence of each content item of interest we used two levels of relative frequency within each textbook: equal to or greater than 1% of the Biology-related content, and less than 1%. The item “cell” was found in 1% or more of the lines of text in all textbooks for all grade levels, with a relative frequency of 7.9% in CSE and 11.65% in PREUB. Other items found in 1% or more of the lines of text in both stages of secondary education were cell division, tissues, and embryonic development, which were present in different proportions depending on the grade level. In CSE textbooks, the item “stem cells” was found in more than 1% of the lines of text in one publisher’s textbook used for 14-year-old students (CSE grade 2) and in the other publisher’s textbook used for 16-year-old students (CSE grade 4). However, this item was absent from both textbooks used in the two PREUB grades.

The items with a relative frequency greater than 1% are relevant to the regenerative medicine paradigm in that they constitute basic concepts for literacy regarding the cell and tissue conceptualization of the human body, and for an understanding of developmental dynamics and processes. The presence of the items “cell” and “cell division” further showed a significant increasing correlation with increasing grade level throughout the two stages of secondary education. This correlation is undoubtedly related with the fact that both cell theory, which postulates the cell as the biological unit of living organisms, and the theory that all cells arise from the division of a pre-existing cell (Mazzarello, 1999) have been viewed since the second half of the nineteenth century as fully consolidated biological theories that give rise to the concepts (and their further elaboration) of tissues and embryological development – items that also had a relative frequency greater than 1% in the textbooks we analyzed. The content themes and items we observed have long been a part of general scientific culture, and of what Zarcadoolas et al., (2005) have called the dominance of cultural literacy within health literacy, in other words, the ability to recognize and use beliefs, customs, and social identity in order to interpret and act on science and health information.

An important novel aspect of the present study is the presence of information about stem cells in more than 1% of the text lines we examined in CSE textbooks. This was found despite the fact that the concept of stem cells, and particularly an awareness of their biological significance in regenerative medicine, is quite recent (Berthiaume, Maguire, & Yarmush, 2011). The inclusion of information about stem cells in textbooks for students between 14 and 16 years of age is thus an important finding, although somewhat surprisingly, we noted that the relative frequency of mentions of stem cells decreased to below 1% in textbooks aimed at older students in the two PREUB grades.

Among the items found in less than 1% of the text lines in both CSE and PREUB textbooks were cell differentiation, extracellular matrix, and cell therapy and tissue engineering. In textbooks for PREUB the relative frequency of cell death, cell-cell contact, growth factors and cell culture was also lower than 1%. Among all themes and items chosen from the manual by Palsson and Bhatia (2004), the only ones that did not appear in any of the textbooks for any of the six grades of secondary education were induction, tissue dynamics, cell migration, cell-matrix interaction, biomaterials, and integration of new tissues in the host organism.

Our analysis of content themes and items shows that the concepts of cell differentiation and extracellular matrix were present in textbooks for both stages of secondary education. These items, together with those identified in 1% or more of the text lines, comprise the basic set of components of human tissues and the underlying biological processes of development, growth and basic functional activity (Kierszenbaum, & Tres, 2015). In addition, it is important to note the presence of textbook content on cell therapy and tissue engineering in both stages of secondary education, given that this area constitutes the conceptual basis of regenerative medicine.

Nevertheless, among the elementary items identified by Langer and Vacanti (1993) as indispensable for a solid scientific and technical understanding of the concept of tissue engineering, the only ones we found in the textbooks studied here were the items “stem cell” (relative frequency of 1% or more) and “growth factors” (relative frequency less than 1%). The item “biomaterials” was absent from all natural science textbooks used in CSE and PREUB. Together, stem cells, biomaterials, and growth factors constitute the basic elements of artificial tissues created in the laboratory for therapeutic application in the new paradigm of regenerative medicine.

We believe that although cell therapy and tissue engineering content is present in both stages of the secondary education curriculum, acquiring a suitable level of scientific literacy in regenerative medicine as part of the process of attaining sufficient health literacy (Zarcadoolas, Pleasant, & Greer, 2005) may be difficult if students are not taught about biomaterials as one of the fundamental content items needed to understand recent developments in regenerative medicine. On a more positive note, textbook coverage of cell culture is relevant to the teaching aim of understanding the scientific and technological foundations that make tissue engineering possible.

Science is one of the fundamental components of the curricular content in the Spanish secondary education system, in both CSE and PREUB grades. The aim of science in these stages of education is to instill in students the importance of scientific culture in their daily life, and to teach them a way of thinking about the universe and ourselves. Science teaching at these grade levels enhances students’ skills in areas related with critical thinking, observation, flexibility and imagination (Donnelly, 2004). Moreover, science teaching constitutes an important challenge for teachers (Harlen, 1997; Murphy et al., 2001; Osborne, & Simon, 1996).

The challenges arise mainly because of the huge volume of scientific knowledge that has been incorporated into the teaching curriculum during the last one hundred years (Aikenhead, 2006; Campbell, 2001; Dewey, 1910). In summary, textbooks used in the teaching curriculum for compulsory and elective secondary education in Spain contained basic information in a reasonably balanced proportion on the basic concepts of cell and tissue biology in the human body, and the information appeared adequate to ensure an understanding of the new paradigm of regenerative medicine. Although mentioned infrequently in the textbooks we analyzed, the item “cell therapy and tissue engineering” was covered, and the items “stem cell” and “growth factor”, which need to be learned as a prerequisite to understanding cell therapy and tissue engineering, also appeared at varying rates of relative frequency. However, the absence of the basic content item “biomaterial” may make it difficult for students to understand the content about tissue engineering, and may thus pose an obstacle to the acquisition of appropriate literacy in the new paradigm of regenerative medicine, and by extension, to literacy more generally in health education and public health policies.

### **5. Conclusions**

One of the most important challenges in science teaching is the incorporation of new scientific paradigms and their translation to middle and secondary school educational materials. In this connection, the incorporation of some of these paradigms has raised complex issues not only because of the complexity of scientific knowledge per se, but also because of the social impact inherent in all scientific knowledge. The incorporation of the theory of evolution, molecular biology, atomic physics or environmental issues, among other topics, has led to considerable debate surrounding the nature of what should and should not be taught, especially in connection with appropriate processes for translating new areas of knowledge to the teaching curriculum (Berti, Toneatti, & Rosati, 2010; Blackwell, Powell, & Dukes, 2003; Yilmaz, Boone, & Andersen, 2004). The approaches used for teacher training in these new paradigms is also a determining factor in this process, as Siitonen et al., (2015) recently found in connection with the rational use of medicines. Identifying the basic concepts of regenerative medicine that are present in educational materials such as textbooks currently used by our students and teachers is also a fundamental part of efforts to determine whether appropriate levels of literacy in this new paradigm are likely to be achieved. Having this information will make it possible to introduce changes in school curricula needed in this area in order to equip students with a sufficient and appropriate grounding in the basic concepts of regenerative medicine so that they can, in the future, make better informed choices and avoid false expectations from therapy

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**Table 1:** Number of lines of text with Biology-related content in textbooks from two publishers (LT1, LT2) used in each of the six grades of secondary education in Spain

		CSE 1	CSE 2	CSE 3	CSE 4	PREUB 1	PREUB 2
<b>Biology lines</b>	<b>LT1</b>	1,292	1,279	1,927	2,759	6,542	11,161
	<b>LT2</b>	2,251	1,614	4,955	4,127	9,085	19,736

**Table 2:** Basic information items relevant to the regenerative medicine paradigm that were present in 1% or more of all lines of text in textbooks from two publishers (LT1, LT2) used in each of the six grades of secondary education in Spain

		CSE 1	CSE 2	CSE 3	CSE 4	PREUB 1	PREUB 2
<b>Cell</b>	<b>LT1</b>	45	82	114	215	341	1300
	<b>LT2</b>	93	110	118	211	122	1603
<b>Cell division</b>	<b>LT1</b>	0	0	0	117	96	394
	<b>LT2</b>	0	0	28	162	61	747
<b>Tissue</b>	<b>LT1</b>	1	0	41	0	524	0
	<b>LT2</b>	2	23	146	5	416	52
<b>Embriology</b>	<b>LT1</b>	4	0	64	60	387	0
	<b>LT2</b>	29	82	3	56	130	0
<b>Stem cells</b>	<b>LT1</b>	0	26	0	0	0	0
	<b>LT2</b>	0	0	26	52	1	94

**Table 3:** Basic information items relevant to the regenerative medicine paradigm that were present in less than 1% of all lines of text in textbooks from two publishers (LT1, LT2) used in each of the six grades of secondary education in Spain

		CSE 1	CSE 2	CSE 3	CSE 4	PREUB 1	PREUB 2
<b>Cell differentiation</b>	<b>LT1</b>	0	0	0	0	0	14
	<b>LT2</b>	0	0	12	3	12	18
<b>Extracellular matrix</b>	<b>LT1</b>	0	3	2	0	24	17
	<b>LT2</b>	0	0	9	0	43	42
<b>Cell therapy and Tissue engineering</b>	<b>LT1</b>	0	0	0	0	0	0
	<b>LT2</b>	0	0	1	0	0	22
<b>Cell death</b>	<b>LT1</b>	0	0	0	0	0	14
	<b>LT2</b>	0	0	0	0	0	73
<b>Cell-cell contact</b>	<b>LT1</b>	0	0	0	0	0	80
	<b>LT2</b>	0	0	0	0	0	54
<b>Growth factor</b>	<b>LT1</b>	0	0	0	0	0	4
	<b>LT2</b>	0	0	0	0	0	3
<b>Cell culture</b>	<b>LT1</b>	0	0	0	0	0	43
	<b>LT2</b>	0	0	0	0	0	39

**Figure 1.** Percentage frequencies of lines of text with Biology-related content in each textbook for each grade of secondary education in Spain. The correlation coefficient in both cases is statistically significant at  $r=0.81$  (LT1) and  $r=0.87$  (LT2).

