Strategies for creativity development in biomedical education through inquiry

Gemma Rodríguez Fabià

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Directors de la tesi:

Dra. Mar Carrió Llach

Dr. Jordi Pérez Sánchez

DEPARTAMENT DE CIENCIES EXPERIMENTALS I DE LA SALUT

Universitat Pompeu Fabra
Barcelona

Agraïments

Ui, la llista és llarguíssima, ja us aviso.

Mar, aquesta tesi és teva. Tu me la vas regalar fa quatre anys. T'he de dir que com a regal, no sé si és molt encertat, és una aposta una mica arriscada. Potser és d'aquells regals que et fan i que no saps ben bé quina cara posar. Per sort, la tesi que em vas regalar no era una cosa material, no existia, era una idea (bé, ara sí que n'hi haurà d'haver una de material a l'estanteria del despatx, espero). Sí, era una idea. Una idea que s'ha convertit en quatre fantàstics anys a nivell personal i laboral. Em vas regalar un "pack". Oferta. Tesi i directora fantàstica *por el precio de uno*. I suma-li al "pack" els afegits: unes quantes hores de feina, estrès, riures, plors, històries, viatges, docència, projectes, classes, alguna copa al sopar de Nadal i karaoke. El JP ja ho diu. "Aquesta, una crack." He après un munt, Mar. Per començar, a fer una tesi, que no en tenia ni idea. He après a fer recerca, que tampoc en tenia molta idea, la veritat (veig que m'estic venent molt bé per futures ofertes laborals). He après com funciona un projecte Europeu (merci, Gema!), les *intringulis* del món acadèmic, també a fer classes de veritat, classes de les bones, classes d'aquelles que surts *a lo Beyoncé*. He après tantes coses de tu que ara el meu CV comença a fer goig. I perquè m'ha tocat *el Gordo*. Una directora llesta, empàtica i constructiva. *¿Qué más se puede pedir?*

He tingut molta sort amb el grup. Està ple de persones guapes. De persones que es preocupen per mi i m'ajuden cada dia. La Mertixell, que m'infla a galetes, em diu *lo estilosa que soy* (els dies que m'arreglo), i que *me habla de sexo* quan necessito desconnectar. El Jordi, que em parla de westerns i pelis de Disney. Que em porta a menjar a los Pescadores, i que em fa riure cada dia que apareix (també em distreu, a vegades). El Josep Eladi, que m'ajuda amb els papers i que em dóna consells d'home savi. L'Eli i el Marcel, *el papa i la mama*, que cada any em porten a Senegal, així com a caprici del mes d'abril, a viure experiències inoblidables amb gent molt interessant. La Nora, la súpermama madrilenya (ai i què simpàtics que sou els de Madrid) que m'ajuda amb estadística i em dóna suport emocional en els moments "durillos", tot inclòs. La Gemma i el Marcel (les noves adquisicions del grup) amb qui he tingut una connexió especial. Marcel, tenim plans de futur, en parlem, no ho oblidis. Gemma, què

contenta que vens sempre, quin riure amb les teves històries. Seràs una “profe” estupenda perquè ets fantàstica.

La feina també m’ha servit per conèixer a gent molt especial. Les Carols (Pozo i Llorente) i l’Amelia. Pozo, les nits amb tu parlant bàsicament de tot fan molta gràcia. Carol, la meva eterna companya de despatx. Gràcies per haver-me ajudat amb tot: amb la feina, amb la tesi, amb la metodologia qualitativa (toma seminari). Gràcies per instaurar els divendres de biquini amb *gossip*. Gràcies pels sopars de formatges i vins. Gràcies per compartir amb mi la deslocalització a l’extraradi. Amelia, lord of lords. Et dec un any de felicitat màxima al despatx (i fora). Quin gust poder anar a banyar-se a la platja i menjar donetes quan estem estressades. Quin gust que sempre riguis. Quin gust que sempre hi siguis. En definitiva, quina sort del HEIRRI (i de que no tinguessis feina).

Emma, ets la persona més guai que he conegut mai (de gran vull ser com tu. Ai calla, que ja en tinc quasi 30...). T’enyoro quan fem els cafè. T’enyoro quan parlem de política. T’enyoro quan parlem de llibres i de teatre (donava bastant de sí, l’esmorzar). Sort que ens queden les Cucine Mandarosso.

Núria. Crec que amb una pàgina d’agraïments no m’hi cap tot el que et diria. Fer una tesi m’ha servit per coneixe’t. Per tant, la tesi ha valgut la pena. Qui ho diria que a la feina hi podries trobar una millor amiga? Quan hi ets, estic més contenta. Sempre t’ho dic. I no exagero. Feina, passejos, berenars, llibres, sèries de caca, viatges, sopars, trucades Austràlia-BCN, notes de veu de 10 minuts, feminisme (i encara més important, reaggeton feminista), llistes de música, dibuixets pel google talk, etc. En definitiva, el pilar bàsic per una noia que és taaaan alta taaaan alta que necessita de bons fonaments. Ah, i gràcies per l’anglès.

Maria, Berta i Juli. Quasi una dècada d’amistat. Maria, quasi-companya de pis gracienc (no ens l’haurien donat tampoc). Maria, amb qui m’entenc sempre. Maria, amb qui comparteixo gustos i hàbits (això de no sortir si hem vingut a menjar i a dormir), amb qui comparteixo caps de setmana a Cadaqués i a Sant Fost. Maria, amb qui parlo quan estic preocupada. Maria, amb qui em desfogo quan estic nerviosa. Maria, amb qui ho compartiria tot. Perquè ens entenem. Berta: individu de gènere femení de caràcter fascinant.

Berta, la valenta. Berta, la que té les històries més rocambolesques i tragicòmiques que he sentit mai. Berta, la que està a milers de km i sempre hi és. Berta, la que sempre escolta i dóna grans consells. Juli, la chica lista. Juli, la chica *Nature*. Juli, l'amiga a la que tots admirem, vaja. No marixis gaire lluny ara quan acabis, que et necessitem sempre a prop.

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Carlos, he fet simbiosi (ha sido sin querer). Mira, necessito que hi siguis sempre. Sempre. Ah, t'ho he dit ja? Sempre.
P.D. Sempre.

Giulia, sólo te voy a decir una cosa: no puedes irte. No quiero hacerte chantaje emocional, pero aquí hay una que no puede vivir sin tí (no quiero imaginarme cómo va a ser eso...).

Marta i Helena, les millors amigues que hom podria demanar. I serà divertit quan tinguem 80 anys, esmorzant i berenant per variar, i encara estiguem encantades d'estar juntes.

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Mama i papa, m'ho heu donat tot. Tot el que que pugui fer o aconseguir és vostre. Us estimo incondicionalment.

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Abstract

Technological and scientific advances produced during the last decades have constituted what scientific research is today. Biomedicine needs innovative professionals to face the challenges raised during this century. Inquiry has been identified as an optimal pedagogical approach to develop 21st century higher order thinking skills such as creativity. In this thesis, we examine how creativity is developed in four different inquiry models (from more guided and subject-based to more open and transdisciplinary) as well as how students' have experienced them. The findings of this thesis evidences positive results regarding creativity development in the four inquiry models, as well as high levels of satisfaction with the learning experience. This thesis provides an insight on how inquiry fosters the acquisition of complex skills. Moreover, this study offers indicators to design inquiry activities devoted to train creativity in biomedical education.

Resum

Els avenços tecnològics i científics que s'han produït durant les últimes dècades han constituït la recerca biomèdica tal i com la coneixem avui en dia. Per poder afrontar els reptes que proposa la ciència, en un futur proper, és necessari formar professionals innovadors en el camp de la biomedicina. Així doncs, la indagació ha estat identificada com una aproximació pedagògica òptima per desenvolupar les competències del segle XXI, com ara el pensament creatiu. En aquesta tesi, hem examinat com es desenvolupa la creativitat en quatre models d'indagació diferents (des de més guiats i disciplinaris fins a més oberts i transdisciplinaris), i també com els estudiants han viscut la implementació d'aquests models. Aquest estudi aporta resultats positius respecte al desenvolupament de la creativitat en els quatre models d'indagació, així com alts nivells de satisfacció amb la metodologia. Aquesta tesi proporciona noves idees sobre com fomentar l'adquisició de competències complexes. A més a més, ofereix uns indicadors i guies per dissenyar activitats d'indagació destinades a la formació en creativitat en l'àmbit de l'educació biomèdica.

Table of contents

1. Introduction

Progress and the phenomenon of rapid change, generated by the technological and scientific advances occurred during the last two centuries, have constituted and defined the modern world. The perpetually changing present that characterises this world leads to the economic challenges, political conflicts, and social problems that postmodern societies experience. This accelerating change has destabilised and dislocated human lives and has produced what is known as a risk society, one in which potential threats have created disorientation and have altered the nature of day-to-day social life, leading to a culture of instability, risk, innovation, and action (Giddens, 1991; Hill, 2001; Wain, 2000, 2008).

This progress has led to continuing problems and crises, has perpetuated the ongoing existence of poverty, of gender and ethnic conflicts and of international disputes, and has increased environmental degradation. And with this we have learnt that the civilization created by the modern world has come to an end, the same civilization that headed towards infinite progress, that advanced with simultaneous developments in science, reason, economy or democracy, and that had unconditional faith in progress and development (Morin, 1999).

But, to consider and to face that the modern world has ended, modern institutions should have also disappeared. However, this is contradicted by the fact that the modern model of university is still alive. Today, higher education institutions try to educate people in terms of logic, objectivity, absolute facts and universal moral values for a rational society (Hossieni & Khalili, 2011). Teachers, in these kind of institutions, are potentially influential: they produce and reproduce knowledge, attitudes and ideology, controlling and preparing students for what is seen as the task of the economic, ideological, and cultural production of future generations (Althusser, 1971; Hill, 2001; Wain, 2000).

Postmodernism has tried to offer, during this late twentieth century, a new explanation of knowledge, school, curriculum and educational content (Hossieni & Khalili, 2011). In fact, education institutions have been identified as essential elements to confront the challenges of the postmodern society. The role of postmodern education is to show that there is no learning which is not, to some extent, vulnerable to error and illusion and that it is, in the form of words, ideas and theories, the fruit of translation or reconstruction by language and thought. This means that paradigms can also lead into illusions and no theory is forever immune to error. Thus, education should strive to develop the ability to detect these sources of error, illusion or blindness (Morin, 1999) in spite of producing the rationally autonomous individual.

This discourse, generated by a number of radical writers and educationists over four decades ago, was grounded on the general concerns of societies living in a perpetually and rapidly changing world. This discourse differed from the one emerged from industry and business, which demanded the training of a new kind of worker responding to the post-industrial society demands in the interest of greater economic efficiency (Ranson, 1992; Wain, 2000). It called for an education that, understood as a continuous and social process of reconstruction or reorganisation of experiences, engaged learners in a critical dialogue and reflection among what was established (Dewey, 1916; Wain, 2008), and differed from modern education where knowledge is blocked, inert and dogmatic, where learning is individual and passive, where environment is unimportant (Wain, 2008). The postmodern idea of education rejects the perception that the main goal of education is to train students' cognitive ability for reason to produce a fully independent functioning citizen, but rather a citizen with a fully social identity. Therefore, education has to encourage an appropriate approach and reflection about why knowledge should be learned, and how it can be questioned, assessed and transformed (Chi Hong Nguyen, 2010).

Despite the fact that during the last forty years some advances have been made in higher education institutions, we are still calling for change in education and learning. And there is a long way to go.

1.1 Creativity

1.1.1 Why is necessary to train creativity in Higher Education?

During the late 20th and early 21st centuries, the revolution experienced by science and technology, which has led to continuous progress and development, has been identified as a crucial influence in the everyday life of postmodern societies and human development.

The success of Western science in predicting and controlling the natural world, and the assumption that “reality” and knowledge are acquired and discovered, essentially, by the scientific method, has validated the premise that the world is reducible into distinct entities and quantifiable (Schwartzman, 1977).The modern idea of science has been perpetuated in Western society, an idea that tends to identify successful science with scientists with deep knowledge of a discipline and mastery of the scientific method (Waldrop, 2015). Actually, this view of science is questionable. The postmodern idea that knowledge and theories are not an absolute truth and the denial of rationalism (Chi Hong Nguyen, 2010) have unveiled other important requirements to match such success. These requirements are the ability to doubt, scepticism, critical thinking, discussion, collaboration towards complexity, communication, or in other words, being creative (in a postmodern understanding of creativity) while making science (Tan, 2009).

The postmodern view of science considers that scientist have to question established theories, combine unrelated knowledge and extend it moving towards the unknown (L. Barrow, 2010). However, some research processes have led to the phenomenon called “incremental science”. This phenomenon explains why some scientists choose to develop ideas that are based only on existing or similar products, instead of questioning what is established and being a source of innovation or new paradigms (Epstein, 2013).

The development of repetitive scientific products and the lack of creativity in this domain is a reality that may have been influenced by modern education and traditional learning. Modern education defines knowledge as the remembering of previously learned material or the body of truth, information, and principles acquired by humankind (Chi Hong Nguyen, 2010), and has treated students as passive learners and absorbers of information (Adams, Beniston, & Childs, 2009a). Thus, the role of education is to pose questions to students challenging traditional assumptions of rationality, certainty and truth. Students must experience active engagement, intellectual excitement, cognitive flexibility (Halpern & Hakel, 2003; Wieman, Adams, & Perkins, 2008), and should be equipped with strategies of scientific inquiry methods with which they can navigate in the large ocean of knowledge (Chi Hong Nguyen, 2010). This way, they will have the opportunity to develop problem solving skills, creative thinking, motivation or persistence, essential abilities to think like creative scientists and to confront the challenges of the postmodern society (Waldrop, 2015).

Different skills have been identified as essential for 21^{st} century challenges. These skills, which are interdependent, have been organised as 1) cognitive skills (problem solving, critical thinking and creativity); 2) intrapersonal skills (metacognitive skills such as self-management, time management, self-development, self-regulation, adaptability); 3) interpersonal skills (complex communication and social skills such as collaboration, teamwork, cultural sensibility, and dealing with diversity) and 4) technical skills (research and information fluency skills, entrepreneurial skills and financial literacy). Thus, collaborative problem-solving, complex-problem solving, digital information and literacy, and creativity have been highlighted as 21^{st} century skills that must be build into curricula, taught and assessed in higher education (Geisinger, 2016).

1.1.2 Different approaches to creativity

The idea of creativity has changed and evolved over the centuries. Until the modern scientific era, creativity was associated to a superhuman force, as creation was attributed to the gods. In fact, the Latin meaning of the verb “inspire” is “to breath into”, reflecting the analogy between the creative process with the moment when the Christian God first breathed life into human (Sawyer, 2006).

But it was not until the 17^{th} and 18^{th} centuries when the conception of creativity distanced itself from the divine idea of creation. During this time, the notion of creativity veered between two different philosophical and cultural movements: rationalism and romanticism. Rationalism believed that creativity was generated by the conscious, deliberating, intelligent rational mind. On the other hand, romanticism thought that creativity emerged from instinct, emotion, freedom and an irrational unconscious, and that reason was an impediment for the creative process (Sawyer, 2006). With the arrival of the 20^{th} century, rationalism was reborn as the modernism movement. Modernism recovered the term *Genius*, previously described by rationalism, to describe creativity. Genius was associated with rational and conscious processes, with both scientists and artists, and was thought to be based on individualism, judgment and memory (Becker, 1990; Sawyer, 2006).

The modern idea of creativity was still accepted during the 1950s and 1960s. At that time, psychologists started searching for tests that could measure a person's creative potential, but they could not develop such a test. This failure, in the 1970s, convinced many psychologists that creativity was a common, every day mechanism, rather than just a distinct trait or mental process. This idea ended with the modern conception of creativity.

Nowadays, creativity is identified by most people as the ability of individuals to generate novel ideas. Nevertheless, creativity is much more than that. As said before, the concept of creativity has proven to be elusive to define. After the 1970s and with the end of the modern understanding of creativity, some psychologists started identifying creativity as a multicomponent process, where several cognitive and affective elements played a part. This perspective stated that the creative act has two phases: a generative phase and an exploratory or evaluative phase (Roskos-Ewoldsen, Black, & Mccwon, 2008). During the generative process, the creative mind pictures a set of novel mental models as potential solutions to a problem. In the exploratory phase, the mind evaluates the multiple options and selects the best one. These two phases, identified by Guilford (1950), were characterized as divergent thinking and convergent thinking. Guilford defined divergent thinking (generative phase) as the ability to produce a broad range of associations to a given stimulus or to arrive at many solutions to a problem. In contrast, convergent thinking (evaluative phase) referred to the ability to focus on the one best solution to a problem (Dehaan, 2009).

The conception of these two stages in the creative process is consistent with results obtained by cognition research, which indicate that there are two distinct modes of thought: associative and analytical. In the associative mode, thinking is defocused, suggestive and intuitive, revealing remote or subtle connections between items that may or may not be correlated, and are usually not causally related. In the analytical mode, thought is focused and evaluative, more conducive to analyzing relationships of cause and effect. Actually, there is ample evidence that the creative process requires both divergent and convergent thinking and that it can be explained by reference to mental abilities and cognitive processes (R. Beghetto & Kaufman, 2013; Kaufman, Richards, & Hospital, 2007; Runco, 2014b; Sawyer, 2006).(R. Beghetto & Kaufman, 2013; Kaufman et al., 2007; Runco, 2014b; Sawyer, 2006)

During the 1980s, the conception of creativity was extended and became more aligned with the postmodern movement. Researchers such as Baron (1981), Harrington (1981) and Amabile (1989) asserted that creativity was a social subject, meaning that social and environmental factors played a crucial role in creativity development (Hossieni & Khalili, 2011). Creativity (or the creative process) was not an individual and isolated process but it was influenced and affected by the creative person, the creative product, and the creative environment (Amabile, 1996; Matthew & Sternberg, 2006; Nakamura & Csikszentmihalyi, 2014).

Recent studies and research on creativity have increasingly highlighted this socio-cultural view (Sawyer, 2006). Creativity is seen as a social and collaborative phenomenon that implies interaction processes with other individuals and is strongly influenced by the environment and its social and cultural properties (R. Hämäläinen & Vähäsantanen, 2011). As Plucker et al. (2004) defined: "Creativity is the interaction among aptitude, process and environment by which an individual or a group produces a perceptible product that is both novel and useful as defined within a social context" (Plucker, Beghetto, & Dow, 2004a). Creativity is the ability to produce something that is both novel and appropriate, and occurs in a collective and collaborative context enhanced by interaction and discussion and influenced by cultural and environmental factors (Dehaan, 2009; Hadzigeorgiou, Fokialis, & Kabouropoulou, 2012; Plucker et al., 2004a; Sawyer, 2006).

The postmodern understanding of creativity emphasizes this approach which, in fact, is aligned with the conception of learning and education that postmodernism supports. Just like a jazz performance emerges from the interactions of different individuals working collaboratively (it could not be created by a single individual), we can speak of the creativity of the individual, but also of the creativity of the ensemble unit (Sawyer, 2006). This means that a group has the potential to be more creative by working together than its members by working separately, because individual knowledge, skills, and abilities are combined. This combination creates new discourses and discussions, and constructs new rules or understandings, promoting change and innovation (Chunfang Zhou, 2012a).

1.1.3 How do we understand creativity in science?

The modern idea of science emphasises the notion that scientists simply discover truth by observing and reflecting on the world (Sawyer, 2006). Hence, to the modern view, science is a game of deduction: taking observations from experience and using them to derive logical propositions and statements about regularities in nature. This conception of science assimilates that science is a body of knowledge. What postmodernism argues is that scientific theories cannot be derived in any simple or mechanical way from observations by an individual, and that scientific knowledge is generated in a cultural context that comes with a set of believes, values and practices (Saywer, 2006; Simmons & Inabinet, 2018). This shift of paradigm has allowed explaining scientific creativity in a new way.

Scientific discovery is the product of creative thinking (Beghetto, Kaufman, Hegarty, Hammond, & Wilcox-Herzog, 2012). In fact, most science discoveries involve slow and methodical work with mini-insights occurring every day, instead of a genius scientist. Scientific progress is a cooperative group effort, involving small contributions from different individuals. Scientific discoveries happen through intensive social interactions between peers with different experiences and backgrounds (Sawyer, 2006). Hence, there is evidence that scientific creativity is complemented with a social dimension, emerges from interacting scientists, and it is considered a socio-related issue. In fact, the image of the lone scientist carrying out experiments in his or her laboratory and experimenting insights is now very unusual and almost a historical myth (Hadzigeorgiou et al., 2012). In contemporary times, interactions among scientists, research groups and disciplines play a catalytic role in the creation of knowledge and facilitate the creative approach (L. Barrow, 2010; Hadzigeorgiou et al., 2012).

Some experts on the field state that the most creative scientists are the ones who are especially good at formulating and asking new questions and solving problems (Sawyer, 2006). This conception consolidates the idea that inquiry is essential to creative thinking. The creative process in science is based on the definition of new scientific problems, the derivation of hypotheses based on existing knowledge, the design of new experiments, the evaluation of evidences and the further verification of theories to explore repertoire, imagine a variety of routes to a solution, and create novel combinations of knowledge or techniques through inductive and deductive reasoning (Hadzigeorgiou, 2005; Hu & Adey, 2002; Huang, Peng, Chen, Tseng, & Hsu, 2017). Scientific creativity can be defined by the creative trait, the creative process of knowledge production, and the creative product, characterised by advances in science knowledge, understanding of scientific phenomena, creation of technical products and scientific problem-solving (Hu & Adey, 2002).

In the science domain, creative and critical thinking have been usually confused, probably because of the definition of critical thinking. Critical thinking has been defined in literature as the mental active process of information perception, analysis, synthesis, and evaluation derived from observation, experience, reflection, and/or reasoning. Critical thinking is also a complex higher order reasoning process that demands different skills, such as questioning knowledge sources, testing information validity, analysing its reliability and drawing appropriate explanations. In fact, critical thinking has been identified as an essential and complementary property of creative thinking. Research has identified that critical thinking has an analysing and evaluative purpose, while creative thinking has a generative aim (Papathanasiou, Kleisiaris, Fradelos, Kakou, & Kourkouta, 2014; Smith, Rama, & Helms, 2018; Wechsler et al., 2018).

1.1.3 Creativity as an approach to respond to complexity

Reality is global, translational, multidimensional, transversal, polydisciplinary, and planetary. However, the modern understanding of realities and problems have lead to what Morin designates as the "paradigm of simplification", where learning and understanding of universal problems have been compartmentalised, piecemeal and disjointed, and consequently, inadequate (Alhadeff-Jones, 2010; Morin, 1999).

Modernism says that any knowledge suggests the selection of significant data and the rejection of non-significant one, separating, uniting, organising into a hierarchy and centralising information (Alhadeff-Jones, 2010; Morin, 1999). This understanding of knowledge and reality dismisses what is local or singular, focuses only on the basic elements of a whole, promotes the absolute sovereignty of order and universal determinism to explain any phenomenon, enhances the absolute reliability of logic to establish the intrinsic truth of theories, isolates the object and its environment, as well as the object from the subject who perceives and conceives it, and eliminates from scientific knowledge the concept of the "self", "being" or "existence". The principle of simplification and modern scientific knowledge contribute to separate science from conscience, establishing a gap between science, philosophy and other disciplines. It also creates a gap between the object of research from the consciousness of the researcher, leading to reinforce the hyper specialisation and perfect order behind the complexity of phenomena (Alhadeff-Jones, 2010; Morin, 1999).

To counteract the modern understanding of this phenomena, Morin proposed "the paradigm of complexity", which stated that if knowledge is to be pertinent, education must elucidate the context, the global, the multidimensional and the complex. The paradigm of complexity embraces the idea that to have meaning, isolated knowledge is not enough and has to be placed in its context, which determines the conditions of its insertion and the limits of its validity. But it is not enough to put knowledge in context, it should be placed also in the global, which is defined as the totally and the whole containing all the interconnected parts and contexts, and which endows these parts with certain qualities and properties. Furthermore, the global is multidimensional, meaning that it includes different elements that should be recognised in knowledge. So, knowledge should be put in context, not isolated from the whole, and it should also include all the dimensions and elements that constitute it (Morin, 1999).

The paradigm of complexity states that pertinent knowledge must confront complexity, understanding the complex as the union of the context, the global and the multidimensional. Understanding the complex whenever the elements that compose a whole are inseparable and interactive. Understanding complexity as the bond between unity and multiplicity. Education must encourage general intelligence to refer to the complex and the context, in a multidimensional way and within a global conception (Morin, 2001).

We were taught to divide, compartmentalise and isolate learning instead of making connections. Interactions and complexities between disciplines became invisible. The natural mental disposition to contextualise and globalise was blocked, and the conversion of the world into disjointed fragments and fractured problems turned the multidimensional into unidimensional and was pushed out of the disciplinary science. Minds shaped by disciplines and fragmented knowledge lost their aptitude to contextualise knowledge and integrate it into its natural entities, and kept us from seeing the global and the essential. This led to a blindness to complex, fundamental, global problems, and this blindness generated countless errors and illusions (Alhadeff-Jones, 2010; Morin, 1999).

Education should encourage the aptitude of the mind to set and solve essential problems and, reciprocally, to understand the multidimensionality of them. In fact, creativity has been identified as a way to understand and respond to the complex and to give to the individual a vision of the whole (Ribeiro Piske et al., 2017). Creative thinking development promotes essential properties to understand the complex and the whole, such as interdisciplinarity, interaction, integration of different perspectives, holistic views, the combination of generation and critical analysis.

1.2 Pedagogical approaches to train creativity in Higher Education: Inquiry as a conceptual framework

1.2.1 How do people learn?

a) The social constructivism theory

During the last decades, a great deal has been learned about the nature of learning. The postmodern constructive perspective rejects the notion of objective knowledge and the view that the locus of knowledge is in the individual. The social constructivism learning theory argues that learning and understanding are inherently social, and that culture and tools such as language are integral to conceptual development (Palincsar, 1998).

This paradigm defines learning as a constructive process in which students construct or reconstruct their knowledge networks building personal interpretations of the world based on prior ideas, experiences and social and collaborative interactions (Carrió et al., 2016; Dolmans, De Grave, Wolfhagen, & Van Der Vleuten, 2005; Vygotsky, 1978; Yew, Chng, & Schmidt, 2011). This social interaction creates the cognitive conflict, which drifts to intellectual development. In fact, the impact of social and cultural factors as well as peer interaction on cognitive development has been recognised, and suggest that learning takes place through active participation in purposeful and collaborative activities (Carrió et al., 2016; Downing, Kwong, Chan, Lam, & Downing, 2009; Piaget, 1977). As Piaget explained in his research, contradiction between the learner's existing understanding and what the learner experiences, gives rise to a disequilibrium that, in turn, leads the learner to question his or her beliefs and try out new ideas. Disequilibrium forces the subject to go beyond his or her current state and strike out in new directions (Palincsar, 1998; Piaget, 1977).

Educational research states that during the learning process, activating prior knowledge structures help students to relate new information to existing knowledge that lead to richer knowledge structures. Learners should be actively involved during this collaborative learning process towards activation of prior knowledge, elaborations and deep learning (Dolmans et al., 2005). In fact, social constructivism advocates that individuals learn naturally when they collaboratively engage to solve problems that concern them. This supports what Vygotsky explained in his research: that individual development, including higher mental functioning, has its origins in social sources, and that as learners participate in a broad range of joint activities and internalise the effects of working together, they acquire new strategies and knowledge of the world and culture (Palincsar, 1998; Vygotsky, 1978). Through assistance, collaboration and mediation, what was once carried out in the interpsychological plane (the social phase), becomes internalised and begins to perform intrapsychological functions and reorganise individual's structures.

Furthermore, to support this view of the socio-cultural theory, Vygotsky introduced the construct of the zone of proximal development (ZPD). The ZPD was defined as the distance that existed between two developmental levels: the actual (referring to the accomplishments that an individual can perform independently), and the potential level of development (referring to what an individual can do with assistance and that is determined through problem solving in collaboration with more capable peers). He identified the productive interactions as the ones that guide instruction toward ZPD (Eun, 2017; Palincsar, 1998).

In summary, from a sociocultural and postmodern perspective, learning and development take place in socially and culturally shaped contexts, which are constantly changing, and there is no generic development that is independent of their communities and their practices.

b) Inquiry and the development of learning in science

The word inquiry is defined as an act or an instance for seeking the truth, to make an investigation, to find knowledge. However, there is a disagreement in the definition of inquiry in the education field. Some researchers have presented their interpretation of inquiry as a teaching strategy and a set of students' skills. Other researchers have identified inquiry as encouraging inquisitiveness, a teaching strategy for motivating learning or a way for stimulating questions by students

(Barrow, 2006). Ministrell (2000) considered inquiry as “the process by which we should know something we did not know before we stared. Even when our investigation fails to find the answer, at least the inquiry should have yielded a greater understanding of factors that are involved in the solution” (Minstrell & Zee, 2000). Considering all these different definitions, some questions arise: Why was inquiry included in education? Why was inquiry determined to favour learning in science?

John Dewey (1938) pioneered the inclusion of inquiry in science education. Dewey postulated that, in education, there was much emphasis on studying facts and concepts and little time to think about science. Thus, he encouraged other teachers to use inquiry as a teaching strategy where students worked collaboratively and were actively involved during the learning process. In this strategy, the teacher adopted the role of facilitator and guide to promote the development of reasoning and thinking, instead of the memorisation of factual knowledge. According to Dewey, students should address problems related to their own experiences, and should become active learners in their searching for answers, through the formation of hypothesis, the collection of data and the formulation of conclusions (Barrow, 2006; Dewey, 1938). Some years later, Schwab (1966) also supported the view of Dewey of teaching science through inquiry. He considered that science should be taught in the same way as science operated. He proposed that students could read reports about research and discuss together about problems, the interpretation of data and conclusions reached by scientists to foster the understanding and discoveries of science in its own context (Barrow, 2006). This idea of inquiry, first postulated by Dewey and Schwab, as an approach to make students work collaboratively as current scientists with a facilitator guiding this process, emphasises the constructivist ideas of learning, where knowledge is built from experience and process, especially in a social context. Hence, knowledge is constructed in settings of joint activity, where people are dedicated to learn and collaborate around shared tasks and issues that matter them and knowledge creation is fundamentally a social process (Zhou & Luo, 2012).

So, inquiry, understood as the systematic approaches used by researchers in an effort to answer their questions of interest (Lederman, Lederman, & Antink, 2013), was considered to favour learning because it promoted fundamental abilities such as identify questions that guide investigations, design and conduct a research, use appropriate methodologies, formulate and revise scientific explanations, analyse alternative explanations and models and defend scientific arguments. And this combination of science processes with scientific knowledge, reasoning and critical thinking allow students to learn, not just the skills needed to apply the acquired knowledge and find a viable solution to a complex problem, but also to construct their knowledge and develop a richer and deeper understanding of science (Barrow, 2006; Chen, Jiang, & Hsu, 2005; Savery, 2006a).

1.2.2 Inquiry and creativity

Inquiry extends beyond the development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analysing data. Inquiry is not the scientific method, which is a fixed set and sequence of steps that individuals follow when attempting to answer a question. Although it includes the traditional science processes, inquiry also refers to the combination of these processes (which vary widely within and across disciplines and fields) with knowledge, reasoning and critical thinking to develop scientific knowledge (Lederman et al., 2013).

What is more, inquiry has been identified to provide conditions for developing creativity during learning processes. It fosters an environment for developing students' science knowledge, understanding the nature of science, understanding and using scientific ways of thinking, and making connections with applications to their world beyond the classroom (Barrow, 2006). During the inquiry process, at least three major aspects have been defined as creative enhancers:

- The problem or question to answer: The point of departure is an open, complex, interdisciplinar and real life problem (Craft, 2005; Zhou, 2012).

- Inquiry is a group learning process: During the process of group collaboration in searching solutions, participants build on each other's ideas to reach an understanding not available to any of the participants initially. Thus, group members must enter into critical and constructive negotiations with each other's suggestions, so well-grounded arguments and counter-arguments need to be shared and critically evaluated through collective talk. These conditions are essential for creative endeavors (Grossen, 2008; Zhou, 2012b)

- The shift from the teaching to facilitation: In inquiry learning processes the teacher acts as a facilitator for student-directed learning rather than teaching. This shift enhances the intention of learners to take ownership of ideas and processes, so they feel creative and able to act independently (Zhou, 2012b). Another essential task of the tutor-facilitator is to simulate students' reflection about their own learning process, so that they can develop metacognitive skills.

Furthermore, to reach successful outcomes during the inquiry process, students need to consider alternative solutions, make choices based on evidences, investigate alternatives in different scenarios and explore new questions (Hämäläinen & Vähäsantanen, 2011). Creative skills used by students throughout inquiry are related to problem-solving and communication, as well as learning autonomy and leadership (Tan, 2009). In summary, the focus of creativity development has been concentrated on the interaction between individuals and the environment (Zhou & Luo, 2012). In fact, to stimulate creativity in an inquiry context and environment, it is important to foster improvisation, collaboration and interaction between peers and guarantee a free, flexible and open environment (Hämäläinen & Vähäsantanen, 2011). It is also essential the tolerance to failure and braveness to take some risks, that is why and emotionally safe environment is required (Daud, Omar, Turiman, & Osman, 2012). So, setting up a positive, democratic, non-dogmatic and doctrinal environment is a key factor for the development of scientific creativity during inquiry processes. In this context, students are not afraid to apply knowledge and solve problems and they feel more autonomous and confident (Hu et al., 2013).

1.3 Teaching methods to train creativity in biomedical studies

1.3.1 A review of creative training in biomedical education

Since creativity has been considered a driver for innovation and a key factor for development, promoting creativity has been suggested as one of the priorities for education systems (Zhou, 2012b). In recent years, some investigations exploring how can educators teach creatively and teach for creativity have been developed and different strategies for creativity training have been implemented (Dehaan, 2009; Ma, 2006; Scott, Leritz, & Mumford, 2004b).

Research shows that different creativity training strategies have been proposed depending on how creativity is understood. One way is to consider creativity as a cognitive process, in which new ideas are generated throughout knowledge. Nevertheless, creativity might also be framed by associational and affective mechanisms, as well as motivational facts that inspire individuals to engage in creative efforts. Furthermore, creativity can also be seen as an outcome of environmental opportunities (Scott et al., 2004b). These different interpretations of creativity and the creative process have influenced the strategies and design of creative training. In the case that creativity is understood as mainly cognitive, and problem-solving is seen as an essential fact, then techniques based on heuristics have been chosen to design creative training (since they are useful when applying expertise). However, if creativity is rather viewed as something more related to associational mechanisms, then imagery techniques have been used for creative training. Although creativity can be seen and interpreted in different ways, some general approaches should be taken into account in creative training: the cognitive, the personality, the motivational and the social and interactional (Scott et al., 2004b). For this reason, in creative training it is essential to consider the different focuses: the person who creates, the creative process, the environmental factors, and the outcome (Zhou, 2012b).

In this context of different creativity frameworks, diverse creative training courses have been designed. Sometimes, theoretical models have given the basis to carry out an integrated and programmatic set of creativity training interventions, seen in programmes developed from lateral thinking theories or creative problem-solving, for example. Other forms of creativity training courses have also been described, for example, the ones which rely on assemblies of independent techniques adapted to specific domains or disciplines (Scott et al., 2004b).

To train creativity in a scientific academic context, it is important to encourage students to ask more questions and foster the development of personal interest questions, investigate causes, effects and consequences of their observations, and generate more high-quality questions associated with their personal lives (Barrow, 2010). One way to foster students' creativity is to use an educational model based on the selection of a long-term motivational problem that students should attempt to solve. Creativity can be developed while students investigate various aspects to resolve the problem (Barrow, 2010). But, even though a lot of theory and research about creative and creativity training exists, few experiences have been carried out in biomedical sciences.

In De Haan's (2009) essay, different experiences about how creativity instruction could be integrated into scientific teaching are described. Some of these experiences are based on small modifications of the traditional lecture to promote active learning and cooperative problem solving. These small modifications are short activities, which can be easily inserted in a lecture, and aim to promote peer-to-peer learning and to increase associative thinking. These activities that can be exemplified as the use of peer instruction, Just-in-Time-Teaching techniques, and student response systems known as "clickers". Other strategies proved to be more effective for enhancing scientific creative skills, imply non-traditional courses that are based on constructivist principles, and are focused in inquiry based instruction, such as problem-based, project-based and case-based learning strategies or "community-based inquiry". In these approaches, students engage in research within a real-world context and they increase their content knowledge and critical thinking skills (Dehaan, 2009; Derting & Ebert-May, 2010; Quitadamo & Kurtz, 2007).

On the other hand, Adams has focused his work on reviewing different approaches and techniques which can be used in biomedical sciences to promote and foster creativity for researchers and professionals of biotechnology companies (Adams et al., 2009a). He proposes to include some stimulatory techniques in interactive group sessions, such as effective brainstorming and checklists; lateral thinking and mind mapping. These techniques promote alternative thinking and the identification of unexpected connections, respectively. The six hats process, which promotes parallel, creative thinking in groups. The morphological analysis promotes a matrix-based approach to problem solving. The more elaborated, synectics and TRIZ techniques, are likely to require expert facilitation. This creative process framework is proposed to train biomedical students during the idea generation process so that they are better prepared to overcome the bottlenecks that confront the biotechnologist in areas of great current significance, such as bioengineering, drug discovery and stem cell research or therapy. This framework was developed by industry representatives and academics in a EU funded project (Create Project, http://www.diegm.uniud.it/create), which aimed to design teaching materials to promote creativity based on "live" industrial cases. After examining different methodologies and techniques, they proposed the "Create Process" approach, which comprises the following five phases:

1. Predisposition: in which an environment and a structure conducive to creativity are established within an organization.

2. External mapping: which involves analysis of the environment outside the organization and identification of new opportunities.

3. Internal mapping: in which analysis of internal resources leads to identification of organizational opportunities and threats.

4. Idea generation: which involves the emergence of ideas.

5. Evaluation: which involves the assessments of the idea generation phase.

1.3.2 Teaching methods to develop creativity skills

There is already some evidence that inclusion of specific creativity training as part of a college curriculum can have positive effects (Hunsaker, 2005). In a detailed meta-analysis, Scott and Mumford (2004) examined 70 instructional interventions designed to enhance and measure creative performance. They confirmed that these interventions can be highly successful in enhancing divergent thinking, problem solving, and imaginative performance. Informing students about the nature of creativity and offering strategies for creative thinking were the most effective components of instruction. Research on creativity and creative thinking development has concluded that pedagogical approaches related to constructivism learning theories (such as social modelling, cooperative learning, and project based techniques) showed the greatest improvement in these kind of learning (Scott et al., 2004b). Thus, instruction that emphasizes student-centered strategies is demonstrably more effective than traditional teaching in promoting creativity skills (Barrow, 2010; Friedman et al., 2010; Waldrop, 2015).

a) Flipped Classroom (FC)

The flipped classroom was defined by Lage et al. (2000) as inverting the classroom to promote that the events that have traditionally taken place inside the classroom, now take place outside the classroom, and vice versa. It is a student-centred learning methodology that encourages higher-order thinking and active students' participation (Chen, Lui, & Martinelli, 2017; Lowell, Utah, Verleger, & Beach, 2013). The flipped classroom emerges from the redefinition of the teacher role in the teaching-learning process and the flexibility of teaching spaces, taking advantage of the multiple possibilities offered by technology and interaction. This methodology proposes to use hybrid methods, where the transmission of knowledge is produced through virtual resources such as self-made videos or texts. Face-to-face classes are used to undertake interactive activities such as problem solving, role-playing games, discussions or collaborative work dynamics to consolidate knowledge (Chen et al., 2017; Khanova, Roth, Rodgers, & Mclaughlin, 2015).

This pedagogical approach is supported by the learning theory of socio-constructivism. Students take an active role during the learning process while the trainer is responsible for guiding the interactions during this process. The flipped-classroom model is based, in part, on students' ability to self-regulate learning before class (pre-class) and the trainer's ability to design interaction activities during class (in-class). This model allows for students to direct their own learning and to develop a set of interlocking core skills promoting critical thinking and creativity development (Khanova et al., 2015), such as problem solving, fluency, flexibility, anticipation, putting ideas into context, reflecting on different perspectives (Burnett & Keller-Mathers, 2017).

b) Problem-Based Learning (PBL)

PBL is an instructional and student-centred approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem (Savery, 2006a). It was originally developed in medical schools to help students integrate basic science and clinical knowledge, as well as to develop clinical reasoning and life long learning skills (Barrows, 1996).

The success of PBL depends on the selection of ill-structured problems and on the tutor that guides the learning process. Researchers define PBL as a focused and experiential learning organised around the investigation, explanation and resolution of meaningful problems in which students work in small collaborative groups and learn what they need to know to solve a problem (Hmelo-Silver, 2004; Savery, 2006a). As the students understand the problem better, they generate hypotheses about possible solutions. During this learning cycle, learners define knowledge deficiencies related to the problem, known as learning issues, that students should research during the self-directed learning part of the process. Afterwards, students have to apply their new knowledge and evaluate their hypothesis on what they have collaboratively learned integrating a wide range of disciplines (Hmelo-Silver, 2004; Savery, 2006a).

The PBL methodology promotes students to share their knowledge, experiences and perspectives with other group members. It facilitates the integration of multiple perspectives as part of the problem-solving process. The PBL learning process addresses the effective development of research and problem-solving skills, refines higher order thinking skills, creative and critical thinking, leadership and team work skills, self-regulated learning habits and metacognition processes, and it increases motivation and engagement for learning (Hmelo-Silver, 2004; Joham & Clarke, 2012; Savery, 2006a). In fact, there appears to be a close connection between the opportunities provided by PBL for developing communication (teamwork and interpersonal), research (problem-solving and self-directing learning), and cognitive (critical thinking and inquiry) skills as well as other generic skills (Murray-Harvey, Curtis, Cattley, & Slee, 2005).

Although the PBL methodology fosters the self-regulated learning, this learning process needs guidance to reach its goals and to allow students to develop this set of skills and knowledge content, which must be provided by a tutor or facilitator. In PBL, tutors are expected to facilitate or activate student learning and effective group functioning by encouraging all members' participation, monitoring the quality of learning and intervening when necessary. The facilitator also plays an active role in the scaffolding of students' learning providing a framework that can be used by students to construct knowledge on their own. Thus, the PBL tutor is crucial to the effectiveness of the learning process (Yew et al., 2011).

The way in which PBL is implemented can be critical for its success in achieving intended learning outcomes. A broad variety of PBL experiences have been described, such as activities inside a subject, activities integrating learning objectives from different subjects, PBL subjects or entire curriculums based on PBL (Hung, 2011).

c) Project-Based Learning (PjBL)

Project-Based Learning is a student-centered approach that models the general process of investigation that scientists use to answer questions in the real world. This method allows students to acquire deep knowledge and to learn different skills through an active exploration of a complex problem (Savery, 2006a). In the PjBL methodology, students learn while working for an extended period of time and investigating to respond to a complex question or problem. This methodology simulates real investigations to make students learn while practicing important skills such as problem-solving, collaboration and interaction, autonomy, considering alternative solutions, investigating different scenarios, exploring new questions and developing creative thinking (R. Hämäläinen & Vähäsantanen, 2011). In fact, PjBL has been promoted as a pedagogy which can both enhance student higher order skills, including self-reflection, critical thinking, the ability to undertake independent inquiry, responsibility for own learning and intellectual growth and maturity (Harvey & Green, 2006; Spronken-Smith & Walker, 2010), as well as as a way to integrate research in teaching where both students and teachers are act as co-learners (Spronken-Smith & Walker, 2010). Thus, the core elements of this methodology are:

- Learning is stimulated by inquiry, driven by questions or problems.

- Learning is based on a process of constructing knowledge and new understanding.

- It is an "active" approach to learning, involving the learning by doing.

- It is a student-centred approach to teaching in which the role of the teacher is to act as a facilitator.

- It involves a move to self-directed learning with students taking increasing responsibility for their learning.

There are different types of PjBL, depending on the nature of inquiry: the level of guidance during the process, the emphasis of learning (existing knowledge or building new one), and its scale (in class, within a course, a whole course, a whole degree). They are classified as 1) structured, where the teacher provides an issue or problem and outlines how to address it; 2) guided, where the teacher provides questions to stimulate inquiry but students are self-directed in terms of exploring these questions; and 3) open, where students formulate these questions as well as going through the full inquiry cycle. The open PjBL is more likely to foster creative skills, as students pursue their own open questions and lines of inquiry, in interaction with the knowledge-base of the discipline (Spronken-Smith & Walker, 2010)

2. Context of study

The Faculty of Health and Life Sciences of Universitat Pompeu Fabra (UPF) was born in 1998 offering an undergraduate Biology Degree focused on the biomedical field and based on an innovative educational project. This faculty, located in a biomedical research environment between the Hospital del Mar and the Barcelona Biomedical Research Park (PRBB), initiated in 2004 a pilot study to adapt its curriculum to the European Higher Education Area (EHEA), a process that finished in 2012. During this period, a hybrid PBL (H-PBL) curricula was implemented with the purpose to foster the development of problem solving skills as well as generic competences such as team working, communication and self-learning skills (Carrió, Larramona, Baños, & Pérez, 2011). With this aim, the 20% of teaching time was devoted to PBL activities, while the remaining time was used in traditional activities such as lectures, lab courses and seminars. Problems that were later used in PBL tutorials were built using the educational objectives of the subjects of each term. All faculty members from different disciplines were involved in this model implementation (Carrió et al., 2011).

In 2008, the fully EHEA-adapted undergraduate degrees of Human Biology and Medicine began. In this environment, and with the arrival of these studies, a consolidated H-PBL curricula was introduced and several learning activities were planned to encourage interprofessionalism among students from both degrees. A series of compulsory PBL courses were implemented. These courses were named Integrated Medicine (MI) I, II, III and IV (Medicine Bachelor), and Integrated Biomedicine (BMI) I, II and III (Human Biology bachelor). While MI I, II, IV and BMI I, II were delivered as bachelor specific and regular PBL courses, MI III and BMI III were fused in order to let students from both degrees work together throughout an open and interprofessional PjBL approach.

This study was performed in the Faculty of Health and Life Sciences (UPF) during the academic years 2014-2015, 2015-2016, 2016-2017 and 2017-2018. Most of the interventions of this study have been implemented in the PBL and PjBL courses MI I, II, III, IV and BMI I, II, III, as well as in some specific subjects of the Human Biology and Medicine Bachelors.

3. Hypothesis and objectives

This thesis hypothesises that inquiry-based educational approaches parting from socially relevant contexts, collaboration, multidisciplinarity and integrating stimulatory and problem-solving techniques, foster the development of creativity.

The general objective of this thesis is to analyse the development of creative skills and creative thinking through pedagogical methodologies based on inquiry and collaborative work in undergraduate biomedical studies. The specific objectives are as follows:

- Describe the conceptualisation of creativity in the biomedical field and identify its pedagogical implications from the point of view of biomedical researchers.

- Analyse the development of creative skills of undergraduate biomedical students in collaborative, problem-solving, and inquiry-based activities designed for the Flipped Classroom implementation in a single and traditional subject.

- Assess the development of generic, research and creative skills in undergraduate Medical and Human biology students through the Problem-Based Learning methodology and identify how creative skills can be trained through the different PBL phases.

- Evaluate the development of research and creative skills, as well as the generation of a creative product in undergraduate biomedical students throughout the implementation of an open and interprofessional Project-Based Learning course in human biology and medicine students. In this context, it will also be assessed the impact of a creativity workshop based on stimulatory techniques.

- Analyse the development of creative thinking throughout a transversal and multidisciplinary scenario in a Project-Based Learning course for PhD students from different disciplines.

4. Methods

This thesis describes and assesses the performance and implementation of four different inquiry models in our faculty, as well as the development of creativity skills through them. Some of these inquiry models have been designed *de novo*, focusing on creativity training, during the progress of this study (Guided activities inquiry model and Transdisciplinary Project-Based Learning model), whereas other models did already exist (Problem-Based Learning model and Interprofessional Project-Based Learning model). In the case of the inquiry models that were already performed in the faculty, some innovations have been introduced in the framework of creativity development.

In this context, this thesis has used a descriptive-evaluative and a educational ethnographic approach within a qualitative research and constructivist paradigm. We have framed this study in the qualitative research paradigm because of the multiparadigmatic, transdisciplinar and multimethod focus of the study, as well as its naturalistic perspective regarding the human experience. We also have used a constructivist paradigm to emphasise the importance of subjective aspects of reality as constructed and interpreted by investigators (Harris, 2003; Nieto-Martín et al., 2010). The descriptive-evaluative research (qualitative and quantitative methods) has been useful to explain deeply the performance of the four different inquiry models, as well as to assess how these models have worked. The educational ethnographic approach has been used to analyse how creativity skills have been developed during the different inquiry models (Nieto-Martín et al., 2010).

4.1.1 The inquiry approach

Four different student-centred and collaborative inquiry models were implemented and assessed in this thesis. These models varied from more structured and discipline-based inquiry approaches to more open and transversal models:

- Guided inquiry activities model: Collaborative and inquiry structured activities in a single subject, performed through the Flipped Classroom methodology. (Chapter 2, page 77)

- Problem-Based Learning model: Guided inquiry through an interdisciplinary problem. (Chapter 3, page 95)

- Interprofessional Project-Based Learning model: open and interprofessional inquiry in the biomedical field, in which human biology students and medical students collaborate to develop a project. (Chapter 4, page 119)

- Transdisciplinary Project-Based Learning model: open and transversal inquiry in which students from experimental sciences, humanities and social sciences fields must develop a project. (Chapter 5, page 147)

4.1.2 The inquiry activities design

Different inquiry activities were designed in each model. First, each inquiry activity parted from a complex problem. These problems (or scenarios) were designed taking into account socially relevant issues. Premise number one (and common point of all the activities) was to include a social dimension. Second, all the activities had to include collaborative work. The second premise was to design a guided learning process were the individuals had to collaborate to reach the desired goal. Finally, these activities had also to include different elements that werer considered creative. Some examples of these elements are the inclusion of different disciplines (in the problem and in the collaborative work), the combination of different collaborative activities, or the integration of stimulatory techniques during the learning process.

4.2 Participants

A total of 1298 participants participated in this thesis. The individuals that collaborated with this study have different profiles. 15 participants are renowned scientists and group leaders of different Catalan research institutions, as well as professors of different Catalan universities. Furthermore, 1229 participants are undergraduate students from the Human Biology Bachelor and the Medicine Bachelor of the Universitat Pompeu Fabra (UPF). These students belonged to the promotions 2011-2012, 2012-2013, 2013-2014, 2014-2015, 2015-2016 and 2016-2017. Of these, 901 are from

Human Biology and 3281 are from Medicine. Besides, 44 professors from UPF, which participated as tutors in Integrated Biomedicine and Medicine I and II, collaborated with this thesis. Finally, 15 participants from different disciplines (experimental sciences, political sciences, humanities, and translation and interpretation) and with different research experiences (PhD students, faculty and senior research staff, research managers, and administration and services staff) also collaborated with this thesis.

4.3 Data collection instruments and analysis

4.3.1 Data collection instruments

Different data collection instruments have been used for the purpose of each study of this thesis.

- Anonymous questionnaires with quantitative closed questions and qualitative open sections were delivered and collected to assess students and tutors' perceptions on different inquiry models.

- Semi-structured interviews were used as a qualitative data collection instrument to deep in individuals' conceptions on different issues.

- Focus groups were used as a qualitative data collection instrument to understand students' learning experience in a specific inquiry model.

- Field notes were obtained during different inquiry activities and were used to describe and evaluate the students' learning experience in each model.

- Students' productions were used to analyse the development of creativity in each inquiry model.

- Students' learning results were used as a quantitative data collection instrument to assess each inquiry model learning experience.

4.3.2 Statistical analysis

This thesis has used statistics and the SPSS software to analyse quantitative data. All this data has been analysed by univariate and bivariate analysis using a descriptive statistics approach. Furthermore, different approaches have been used taking into account the objective of the study. To analyse the correlation between the quantitative variables, the Pearson correlation was used as all the variables in this thesis have a linear relation. Also, to examine if there were significant differences on gender and between medical and biological students, the independent samples T-Test and Mann Whitney U Test were used depending on the variable (Connolly, 2007). Furthermore, to assess if there were significant differences between the learning results obtained within traditional or student-centred methodologies, the non-parametric Wilcoxon test for non-parametric samples have been used.

4.3.3 Qualitative Content Analysis (QCA)

To analyse the qualitative data from the semi-structured interviews, focus groups, students' comments, and field notes, the qualitative content analysis approach was used as a technique within a constructivist paradigm using the Atlas.ti software. The qualitative content analysis is a technique to classify written or oral materials into identified categories or similar meanings. It is based on the interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns for systematically describing the meaning of qualitative material. As a research method, the QCA has been useful to represent a systematic and objective description of phenomena. All the data of this thesis has been reduced to concepts that describe the research phenomenon by creating categories and codes. All codes and categories that emerged during the analysis were refined after multiple iterations of coding of the content and have been triangulated by other group members (Elo et al., 2014; Ulla H. Graneheim, Lindgren, & Lundman, 2017; Ulla Hallgren Graneheim & Lundman, 2004).

a) Analysis of creative skills developed in the different inquiry approaches

To analyse the development of creative skills in the different inquiry approaches, an adaptation of the theoretical framework on *Integrating creative thinking skills into the Higher Education classroom* has been used (Burnett & Keller-Mathers, 2017). This model emphasises the idea that creativity is a complex and multifaceted topic and that researchers have identified a high number of different but overlapping set of skills that shape creative thinking. Table 1 shows the set of creative skills used in this thesis.

Table 1: Description of creative skills adapted from Burnett and Keller-Mathers (2017).

Creative skills	**Description**
Problem-solving	Aware of a challenge or opportunity: define problems
Produce and consider many alternatives	Fluency, generating many options
Societal	Considering the societal-related issues of the problem
Be flexible	Generating variety, different categories and perspectives
Be original	Statistical infrequent responses; novel, unusal perspectives
Highlight the essence	The absolutely essential; synthesizing all, focusing on one
Elaborate but not excessively	Adding or developing details or ideas
Keep an open mind	Resisting premature closure
Be aware of emotions	Recognizing cues, understanding through feelings
Put ideas into context	Putting parts of an experience into a large framework
Combine and synthesise	Putting together new connections with the given elements
Look at it another way	Seeing from a new or different perspective
Break through-Expand the boundaries	Changing the paradigm; going outside given requirements
Visualize it	Uisng vivid, colourful imagery
Enjoy and use fantasy	Imagine, play and consider the nonexistent
Visualize the inside	Describing the inside of things, seeing internal dynamic workings
Get glimpses of the future	Wonder, dream, explore possibilities that do not exits

b) Analysis of the students' productions

Finally, to assess the scientific creativity of students' research projects, we used Hu and Adey's model (Hu & Adey, 2002), taking into account, first, the products developed (technical product, advance in science knowledge, understanding of scientific phenomena, and scientific problem solving) and their level of creativity g (calculated by the mean of *originality*, defined as an answer that is rare, which occurs occasionally in a given population, the *value*, defined as importance in a given context, and *usefulness*, defined as the aptitude to satisfy a need). (Hu & Adey, 2002; Plucker et al., 2004a)

5. Results

Chapter I. Creativity in Biomedical Education: Senior Teaching and Research Staff's Conceptualization and Implications for Pedagogy Development

Rodríguez G, Zhou, C, Carrió M. Creativity in Biomedical Education: Senior Teaching and Research Staff's Conceptualization and Implications for Pedagogy Development**.** *International Journal of Engineering Education*. 2017; 33(1):30-43.

Summary

As an emerging new interdisciplinary area, biomedical education has been recently paid a growing attention to its curriculum design. Creativity has been suggested as a key element in its pedagogy development. This paper will focus on a research question: how do the senior teaching and research staff conceptualize ‘creativity’ in relation to their daily working experience and based on such conceptualizations, what are the implications for pedagogy development in biomedical education? Theoretically, we will take a departure of social-cultural approach to creativity that emphasizes shaping roles of environmental influences on creativity in a specific context of interdisciplinary teaching and learning, such as biomedical education. An empirical study by qualitative interviews (n=15) with senior research and teaching staff at different Spanish institutions will further help to provide evidence that guides to answer the research question. The data analysis shows that creativity should be an essential element in curriculum and there are needs of creativity training programmes in biomedical education. Meanwhile, pedagogical changes should be towards encouraging collaborative work, critical thinking, problem solving by creative problem-based learning scenarios, promoting autonomy in applicable and useful projects, working with creative articles in their fields, fostering experiments design at university, and developing new evaluation systems, which underpins the necessity of providing a systematic educational environment for creativity development in future biomedical education.

Chapter 2. Flipped classroom: Fostering creative skills in undergraduate students of health sciences

Rodríguez G, Díez J, Pérez N, Diéz J, Baños JE, Carrió M.

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Chapter 3. Effect of PBL implementation on the students' and teachers' beliefs of 21st century skills improvement

Rodríguez G, Baños JE, Carrió M.

Manuscript

Summary

Problem based learning (PBL) provides an encouraging learning environment to develop generic, research and creative thinking skills, identified as essential for the 21st century challenges. However, the characteristics of PBL implementation into the curriculum can be critical to achieve these outcomes. This study explores the effects of shifting the implementation of PBL from a PBL-Module integrated within traditional subjects to a full interdisciplinary PBL-Courses in undergraduate health sciences students.

Students' and tutors' perceptions on the acquisition of these set of skills as well as the satisfaction with the learning experience were collected through surveys and compared in both models, the PBL-Module with 364 participants and the PBL-Courses with 287 participants.

Results showed that in interdisciplinary PBL-Courses, the perception of skills improvement, the satisfaction with the course and the PBL usefulness are increased in both students and teachers. It has also been identified a strong correlation between the acquisition of generic and research skills and the perception of the PBL usefulness and the satisfaction with the experience. The study also showed how creative skills are developed during the different PBL phases.

This study provides new evidence on the PBL characteristics that favours the development of these skills.

1. Introduction

Social constructivism defines learning as a constructive process in which students construct or reconstruct their knowledge networks building personal interpretations of the world based on prior ideas, experiences and social and collaborative interactions (Carrió et al., 2016; Dolmans, De Grave, Wolfhagen, & Van Der Vleuten, 2005; Vygotsky, 1978; Yew, Chng, & Schmidt, 2011). The impact of social and cultural factors as well as peer interaction on cognitive development has been recognised and suggest that learning takes place through active participation in purposeful and collaborative activities (Carrió et al., 2016; Downing, Kwong, Chan, Lam, & Downing, 2009; Piaget, 1977).

Educational research states that activating prior knowledge structures help students to relate new information to existing knowledge that leads to richer knowledge structures. Learners should be involved actively during this learning process towards activation of prior knowledge (Dolmans et al., 2005). In fact, social constructivism advocates that individuals learn naturally when they are engaged in solving problems that concern them. Pedagogical approaches such as active learning strategies, whereby students are engaged in meaningful activities as part of their learning process and which have been defined as "doing things and thinking about what they are doing", are more effective than passive learning in the process of knowledge construction (Carrió et al., 2016; Derting & Ebert-May, 2010; Yew et al., 2011). Problem-Based Learning (PBL) have been used in this learning paradigm.

PBL empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem (Savery, 2006b). Researchers define PBL as a focused and experiential learning organised around the investigation, explanation and resolution of meaningful problems in which students work in small collaborative groups and learn what they need to know to solve a problem (Hmelo-Silver, 2004; Savery, 2006b). As the students understand the problem better, they generate hypotheses about possible solutions. During this learning cycle learners define knowledge deficiencies related to the problem, known as learning issues that students should research during the self-directed learning part of the process. Afterwards, students have to apply their new knowledge and evaluate their hypothesis on what they have learned in collaboration and integrating a wide range of disciplines (Hmelo-Silver, 2004; Savery, 2006b).

The PBL methodology promotes most of the skills that have been identified as essential for 21st century challenges. These are focused in cognitive skills (non-routine problem solving, critical thinking and creativity); intrapersonal skills (metacognitive skills such as self-management, time management, self-development, self-regulation and adaptability); interpersonal skills (complex communication and social skills such as collaboration, teamwork, cultural sensibility, and dealing with diversity) and technical skills (research and information fluency skills, as well as entrepreneurial skills). These have been highlighted as 21st century skills that must be built into curricula, taught and assessed in higher education (Geisinger, 2016).

As PBL promotes students to share their knowledge, experiences and perspectives with other group members it facilitates the integration of multiple perspectives as part of the problem-solving process. The PBL learning process addresses the effective development of research and problem-solving skills, refines higher order thinking skills, creative and critical thinking, leadership and team work skills, self-regulated learning habits and metacognition processes as well as increases motivation and engagement for learning (Hmelo-Silver, 2004; Joham & Clarke, 2012; Savery, 2006b). In fact, there appears to be a close connection between the opportunities provided by PBL for developing communication (teamwork and interpersonal), research (problem-solving and self-directing learning), and cognitive (critical thinking and inquiry) skills (Murray-Harvey et al., 2005).

Although the PBL methodology fosters the self-regulation of learning, this learning process needs guidance to reach its goals and allow students to develop this set of skills and knowledge content, which must be provided by a tutor. In PBL, tutors are expected to facilitate or activate student learning and effective group functioning by encouraging all members' participation, monitoring the quality of learning and intervening when necessary. The facilitator also plays an active role in the scaffolding of students' learning providing a framework that can be used by students to construct knowledge on their own. Thus, the PBL tutor is thought to be crucial to be effective (Chng, Yew, & Schmidt, 2014; Schmidt, Rotgans, & Yew, 2011).

The way in which PBL is implemented in the curricula and the educational settings can be critical for its success in achieving intended learning outcomes. A broad variety of PBL instructional designs have been described, such as problem-solving activities inside a subject, PBL modules integrating learning objectives from different subjects, PBL courses or entire curriculums based on PBL. According to the degrees of self-directedness learning processes and problem structuredness, different PBL models have also been used (Barrows, 1996). Issues related to human factors, such as students' and tutors' behaviors, small group interactions and resources and workload, might also affect students learning outcomes. So, when implementing PBL it is important to consider which model will produce the desired effects, considering the learners' characteristics and the instructional needs (Hung, 2011)

In our school, we started the PBL implementation in Bachelor of Biology students using a model that used problems with contents and objectives from different subjects, that we called the PBL-module (Carrió et al., 2016). The results of this experience showed us that students needed more *feedback* and guidance in metacognition processes by tutors, a better clarification of evaluation criteria, and tools for self-assessment and of promoting creative thinking (Carrió et al., 2018). As a consequence, a new PBL implementation strategy was introduced with the new Bachelors' of Human Biology (that substituted the Bachelor of Biology) and Medicine on 2008-2009, which pretended to foster the development of generic and research skills and creative thinking. The main changes implemented in the new model aiming to improve the identified dysfunctions were: 1) Interdisciplinary PBL courses of 10 weeks were introduced in the curriculum, 2) each group of students had the same tutor during all the course, 3) the evaluation process included metacognitive activities, such as self and peer assessment through rubrics or written reflections about their learning process. We called this strategy the PBL-courses.

This study hypothesises that the development of generic, research and creative thinking skills are enhanced in interdisciplinary PBL-courses and the overall satisfaction with the learning experience increases. In this paper, we explore whether changing the characteristics of the PBL implementation, the desired students learning outcomes improve. Specifically, we examine the perceptions of the students and tutors on the acquisition of generic, research and creative thinking skills through PBL-courses, as well as assessing the satisfaction of students and tutors with this pedagogical approach.

2. Methods

2.1. Research Context

In 2004, our school started a pilot study that consisted in introducing PBL activities in the curriculum of the Bachelor in Biology to explore the feasibility of creating a hybrid model of teaching that included PBL with traditional lecture-based model. In the pilot study, 20% of the teaching time was devoted to PBL tutorials, whereas the remaining was used in activities such as lectures, lab courses and seminars. An integrated module, with interdisciplinary problems including learning outcomes from the different subjects of the term was designed. All the faculty members participated in the problem design and supervised PBL activities as tutors. In this model each tutor participated in only one PBL case and a new tutor was assigned for the new case for each group (Carrió, Larramona, Baños, & Pérez, 2011, Carrió, 2016). In the context of this article, we called this pilot study the PBL-module.

With the implementation of the new Bachelors in Human Biology and in Medicine following the Higher Education European Space in 2008-2009, the hybrid PBL model shifted to the implementation of two PBL courses subjects in Human Biology (Integrated Biomedicine I and II) and in Medicine (Integrated Medicine I, II and IV), as well as the introduction of a project-based learning course in each Bachelor (Integrated Biomedicine III/Medicine III). This new schema pretended to foster the development of generic and research skills as well as the critical thinking. Each course had four ECTS and lasted ten weeks, the students worked in groups of 8-10 students with a tutor acting as a learning facilitator (the same during the whole course) and solved four interdisciplinary problems. Different assessment tasks were planned, including self- and peer-assessment of students on their participation in the PBL tutorials, written reports, oral presentations and final exams. This strategy was called PBL-courses in the context of this article.

2.2. Participants

This project was carried out during the academic years 2014–2015, 2015-2016 and 2016-2017. The students enrolled in these academic years were asked to answer a survey and two hundred seventy-seven students accepted (72%). Of these, one hundred thirty-three were from the Bachelor in Human Biology (HB) and one hundred forty-four from the Bachelor in Medicine (M). All the HB participants of this study carried out the courses Integrated Biomedicine I and II, while all the medical participants carried out the courses Integrated Medicine I and II. Students had similar academic profiles, using the University entry examination score (Table 1). Furthermore, the tutors that participated in these courses were also asked to participate. Ten tutors out of twenty (50%) accepted. Some data was obtained from a previous study based on the pilot experience (PBL module) in the academic years 2005-2006, 2006-2007 and 2007-2008. In this study, 330 students and 34 tutors participated.

Table 1. Academic characteristics of the students of the PBL-courses * Maximum score was 14. HB: Human Biology; M: Medicine

Cohort	**Students (n)**		**University entry examinations scores***	
	HB	**M**	**HB**	**M**
2014-2015	45	49	11.5	11.8
2015-2016	42	46	11.6	12.3
2016-2017	46	49	12.1	12.6

2.5. Data Collection

This study used a descriptive-evaluative research based on the combination of quantitative statistical techniques and qualitative content analysis research methods. Empirical data were collected through an anonymous questionnaire, delivered to the students and tutors that participated in the PBL subjects at the end of the courses. The questionnaire included several closed-ended questions and an open section of general comments and opinions. Participants scored from 0 (none) to 10 (very much) each item included in the closed-ended questions. Its dimensions were:

- Skills development:
    - Research Skills: Identification of a relevant research question, hypothesis foundation, data collection, and analysis and discussion of findings.
    - Generic Skills: Oral communication, writing ability, teamwork, critical search of information, time management and autonomy.
- Group dynamics: Participants scored their agreement to the following statements: "During the brainstorming session, the ideas of all group members have been considered", "All group members have contributed to the research", "All relevant aspects have been discussed with all the group and a common synthesis have done" and "All group members have collaborated in the elaboration of the final report".
- Learning Experience.
    - Satisfaction with the PBL activity
    - Usefulness of the PBL activity

In the open section part of the questionnaire, participants commented the following dimensions:

- Development of creative Thinking Skills. Participant answered the question: *Do you consider that the Problem-Based Learning approach has contributed to develop your/the students' creative skills? justify it.*
- PBL strengths and weaknesses

- Open comments and opinions

Besides, data and results obtained from the previous study based on the PBL-module using the same questionnaire to compare both models of implementation were used (Carrió et al., 2011; Mar Carrió et al., 2016, Carrió 2018).

In addition, filed notes taken from participant observation on the tutorial sessions were collected to complement the qualitative results and analyze the development of creative thinking skills during the different PBL phases.

2.6. Data analysis

Data analysis was performed through qualitative and quantitative analysis. The SPSS software was used to carry out the statistical analysis. To analyse the correlation between the quantitative variables, the Pearson correlation was used as all the variables have a linear relation. Also, to examine if there were differences between medical and biological students, the independent samples T-Test and Mann Whitney U Test were used depending on the variable (Connolly, 2007). Furthermore, to analyse the students' and tutors' comments, the qualitative content analysis approach was used as a technique within a constructivist paradigm. Codes and categories that emerged during the analysis were refined after multiple iterations of coding of the content (Elo et al., 2014; Ulla H. Graneheim et al., 2017; Ulla Hallgren Graneheim & Lundman, 2004).

For the analysis of the creative thinking skills through PBL phases, the process of codification was guided by the Burnett and Keller-Mathers (2017) framework (Burnett & Keller-Mathers, 2017). Creative skills described by this framework were identified through students and tutors' comments and field notes from PBL tutorials observations.

2.7. Ethics Statement

The Academic Coordination Office board of the School of Health and Life Sciences approved the study protocol. The protocol required that: participants were informed of the objective and the methods of the research; student and tutors' participation was voluntary and anonymous; students and professors were initially blinded to who participated and who did not; and students had no consequences due to their decision in any way. Participants were later informed of the study characteristics, gave their oral consent to participate, and accepted to follow study requirements. Since participation was voluntary and all data collected were kept anonymous, written informed consent was not considered necessary.

3. Results

3.1. Comparison between the PBL-Module and PBL-Courses

3.1.1. Generic and Research skills dimensions

Figure 1 shows the scores given by students to each skill included under the dimension Generic Skills dimension. In all of them, the scores of PBL-courses were significantly higher than those of PBL-module approach. The same happened in the skills of the dimension Research Skills where students from PBL courses gave higher scores than those from PBL-module (Figure 2).

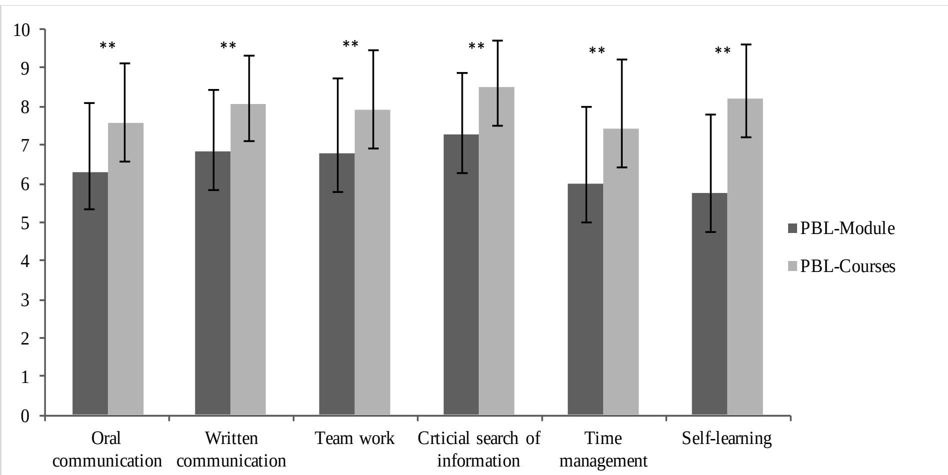

Figure 1. Mean scores given by students in the Generic Skills dimension in the PBL-Module (n=233 students) and PBL-Courses (n=277 students). ** $p<0.01$

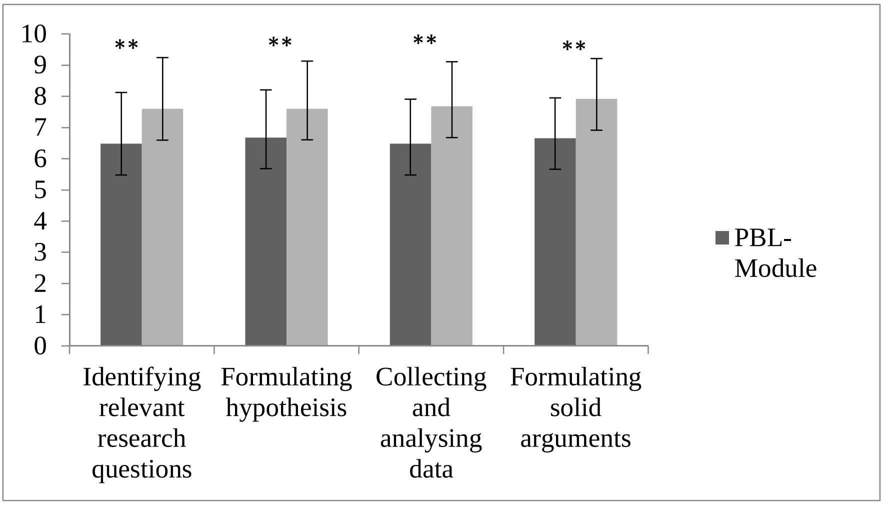

Figure 2. Mean scores given by students in the Research Skills dimension in the PBL-Module (n=233 students) and PBL-Courses (n=277 students). ** $p<0.01$

Table 2 shows the students' and tutors' perception on the variables Generic and Research skills development in the two models of PBL implementation. As it is shown in table 2, the students in PBL-Courses assessed the development of Generic and Research skills dimensions with high scores (mean of 7.96 and 7.70, respectively), which were significantly higher than those that participated in the PBL-Module (mean of 6.63 and 6.57, respectively).

Table 2. Statistical analysis of the scores given by students (S) and tutors (T) on their perceptions on the development of skills included in the Generic and Research Skills dimensions, as well as the Learning Experience dimension in the PBL-Module (n=330 students, n=34 tutors) and the PBL-Courses (n=277 students, n=10 tutors). See Methods section for details.

	Skills development				**Learning experience**			
	Generic skills		Research skills		Satisfaction		Usefulness	
PBL-Module	S	T	S	T	S	T	S	T
Mean	6.63	7.03	6.57	6.83	5.41	7.52	5.77	7.73
Median	6.80	7.12	6.75	7.00	6.00	8.00	6.00	8.00
SD	1.34	1.14	1.17	1.17	1.97	1.60	2.03	1.55
Variance	1.81	1.30	1.38	1.37	3.90	2.55	4.14	2.40
PBL-Courses								
Mean	7.96	8.13	7.70	8.15	7.75	9.20	8.27	9.30
Median	8.00	8.00	7.75	8.25	8.00	9.00	9.00	9.50
SD	1.00	0.37	1.25	0.43	1.82	0.63	1.61	0.82
Variance	1.00	0.14	1.57	0.18	3.32	0.40	2.59	0.68

The tutors' perception of the development of generic and research skills through PBL scored higher than students in both PBL-Module and PBL-Courses. Significant differences have also been found between the perception of the tutors that participated in the PBL-Courses and the ones that participated in the PBL-Module. Tutors perceived than generic and research skills were better developed in PBL-Courses (means of 8.13 and 8.15, respectively, non significant differences were found) than in the PBL-Module (means of 7.03 and 6.83, respectively, non significant differences were found).

3.1.2. Learning experience dimension

The students' and tutors' satisfaction and usefulness of the PBL approaches are depicted in Table 2. The students' perception has shown high scores in the variables of satisfaction and usefulness in the PBL-Courses (means of 7.75 and 8.27, respectively). These values are significantly higher than those obtained with the PBL-Module (means of 5.41 and 5.77, respectively).

Tutors scored both variables higher than the students. The tutors scored the satisfaction and usefulness of the methodology with higher scores in PBL-Courses (mean of 9.20 and 9.30, respectively) than in PBL-Module (means of 7.52 and 7.73, respectively).

3.2. Analysis of PBL-Courses

3.2.1. Comparison between HB and M students

PBL-Courses were implemented both in HB and M Bachelors. The students' perception of the Skills Development and the Learning Experience dimensions are shown in Figure 3. Statistical differences were found between HB and M students in satisfaction and usefulness variables. HB students scored them with a 7.40 and 8.02 while M students have scored these items with 8.08 and 8.51, respectively.

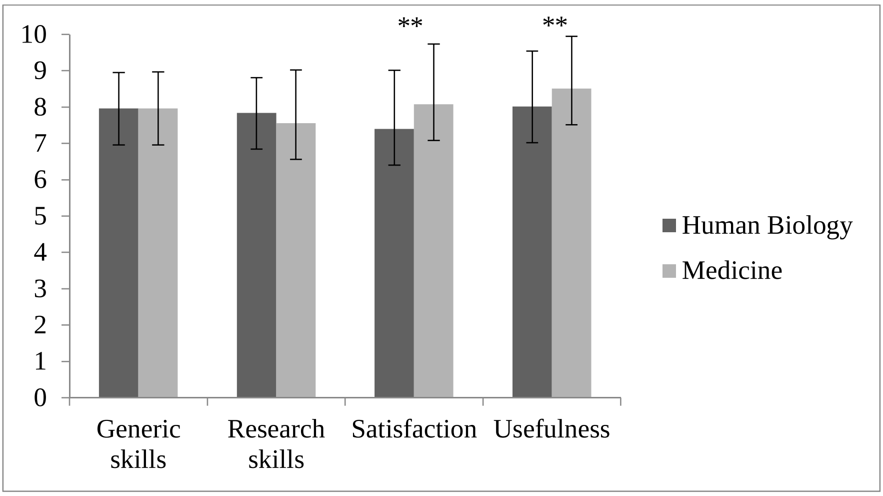

Figure 3. Scores of Human Biology (n=133) and Medicine (n= 144) students' perceptions of the development of Generic and Research skills and Learning experience dimensions (satisfaction and usefulness variables) in PBL-Courses. Data are expressed as mean and SD. ** $p<0.01$ *(Satisfaction p=0.01, Usefulness p= 0.005).*

3.2.2 Assessment of group dynamics dimension

Group dynamics was assessed to identify whether the group was working cooperatively. Students and tutors scored high levels of group dynamics (mean of 7.78 and 8.12, respectively), which indicates that the learning process was not affected by the dysfunctional group interaction. Four different items of group dynamics were assed, and all of them were rated high (from 7.57 to 8.43), as it is shown in Figure 4. No differences between HB and M students were found.

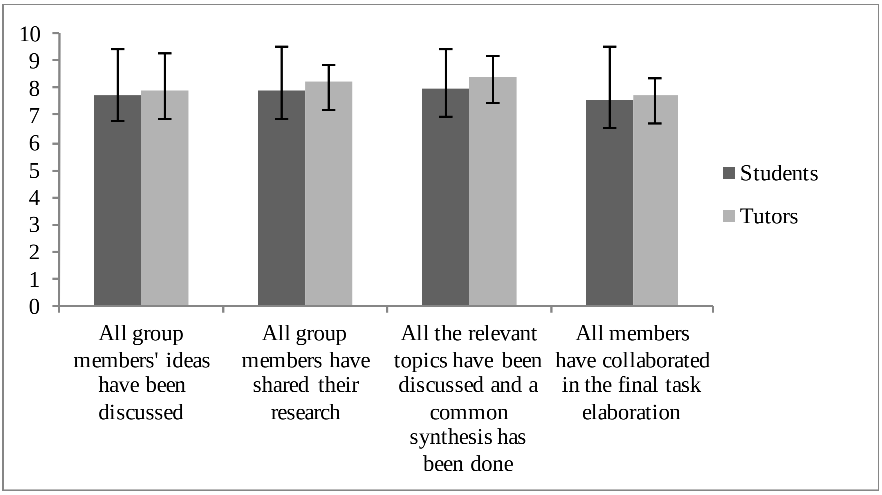

Figure 4. Assessment of the students' and tutors' perception of the development of group dynamics in the PBL-Courses (n=277 students, n= 10 tutors). Data are expressed as mean and SD of each variable.

3.2.3. Correlations among skills development and learning experience

Table 3 shows the correlation analysis. All the correlations between the analysed variables in PBL courses were statistically significant (0.01 level). A strong correlation (>0.6) has been found between the development of generic and research skills (r=0.62**). Besides, statistically significant (0.01 level) medium correlations (0.3-0.6) were found between the level of the group dynamics and the development of generic and research skills.

In addition, the results show a strong correlation between the satisfaction with the PBL courses and the usefulness of them (r=0.767**). Other significant correlations have been found between the satisfaction and the development of generic and research skills (r=0.509**, r=0.558**) and between the usefulness of the courses and the development of generic and research skills (r=0.444**, r=0.567**).

Table 3. Pearson correlation analysis between the perception of students of the development of generic skills, research skills, group dynamics and their evaluation of satisfaction and usefulness of the PBL courses (n=277 students). ** 0.01 (bilateral).

	Generic skills	**Research skills**	**Group dynamics**	**Satisfaction**	**Usefulness**
Generic skills	r=1	-	-	-	-
Research skills	r=0.622**	r=1	-	-	-
Group dynamics	r=0.416**	r=0.354**	r=1	-	-
Satisfaction	r=0.509**	r=0.558**	r=0.444**	r=1	-
Usefulness	r=0.444**	r=0.567**	r=0.333**	r=0.767**	r=1

3.2.4. Development of creative thinking skills

As it is shown in figure 5, 86% of the students think that PBL has contributed to develop their creative thinking skills and 14% think that they did not. Tutors are less convinced in this aspect, 61% of them agree that PBL fostered students' creative thinking, but 32% think that the courses had no contribution in this skill. To complement these data, qualitative analysis of students' comments together with the analysis of the filed notes taken in the PBL tutorial sessions observation, allowed us to describe how creative skills are developed throughout the different PBL phases (Table 4).

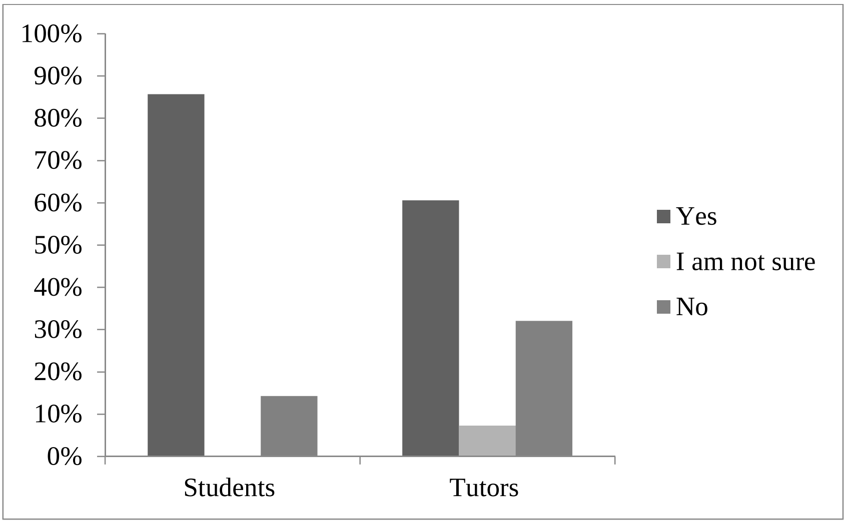

Figure 5. PBL-Courses students' and tutors' responses to the question: Do you consider that the PBL approach has contributed to develop your/the students' creative skills? (n=277 students, n= 10 tutors). Data are expressed as percentages.

Table 4. Development of creative skills in PBL (+, low grade of development; ++, medium grade of development; +++, high grade of development).

PBL Phases	Creative Skills	Findings
Phase 1. Problem presentation and brainstorming	Problem-solving + + +	Students define a problematic situation—the PBL scenario—and analyse different ways to address the problem.
	Produce and consider many alternatives +++	Students generate many options and ideas that could be related to the PBL scenario through a Brainstorming.
	Be flexible ++	After the brainstorming, students identify and generate different categories of ideas to organise the many alternative solutions to the problematic situation.
	Combine and synthesise ++	Students put together and make connections between the different ideas and categories to design a working plan.
	Societal +	Students identify science and society aspects of the presented problem.

Phase 2. Sharing the results and answer the research questions	Highlighting the essence + + +	Students share the research they have done during the week with the peers, analysing and exposing the essence of their research.
	Elaborate- But not Excessively +++	During the discussion, students add information and develop more the ideas and research presented in this session.
	Keep open ++	Students keep open to the emergence of new ideas or perspectives as solution of the problematic situation during and after the collaborative discussion.
	Combine and synthesise ++	Students put together all the discussed information and combine previous and new ideas to elaborate a new working plan.
Phase 3. Elaborating the final conclusions	Be original ++	Students use originality to propose three main complex questions.
	Highlighting the essence + + +	Students analysed critically all the research they have done and expose the essence in the final PBL task.
	Combine and synthesise +++	Students combine and synthesise all the information to formulate and answer three complex questions in the final PBL task.
	Put ideas into context +++	Students relate all concrete research and information as well as the complex questions with a bigger framework, the problematic situation.
	Be aware of emotions ++	Students talk about their feelings regarding the learning process in an autoevaluation session.

3.2.5. Qualitative analysis of the implementation of PBL-Courses

The development of generic and research skills has been also analysed with qualitative data obtained from the students' comments of PBL-Courses. In this analysis, two main categories have been identified: the learning process and the learning outcomes.

Students highlight the benefits of social interactions in the process of knowledge construction that takes place in PBL cycle, they comment that working with peers makes them integrate each one ideas, perspectives and points of view. They also recognize that having to analyze, cooperatively, the situation and propose ideas to apply and integrate knowledge from different fields to look for a solution of the problem facilitates their learning process. Some examples of cites are: *“Through cooperative work we learn to share and collaborate and also to integrate each one ideas”, or “We learn while solving in group a problem with knowledge that we have to look for first, and then apply”.*

Students identify generic and research skills as the main learning outcomes. They are aware about their own development of generic skills, such as cooperative work, communication skills, critical search of information, and self-directed learning, as is seen in their comments “*We learn to dialogue and communicate better between us”* and *“It powers our autodidactic ability, we have to know what we have to learn”*. They also gain experience in research skills, in formulating hypothesis from an unstructured scenario, analysing problems and looking for solutions and evaluating their final outcome, as they pointed out “*We have learned how to analyse complex mechanisms”* and *“We have to think in new questions and discuss what we know to solve a problem”*. Integrating different perspectives, formulating new ideas, relating knowledge from different fields, and doing research makes students develop their creative thinking as they indicate: “*We make questions and we do research on them, so we analyse knowledge deeply and we can think and reflect differently than before”, “Working with different peers make us integrate different perspectives and think different hypothesis and questions”.*

The students’ learning experience through the PBL methodology has been also analysed with qualitative data obtained from the students’ comments. Five main categories have ben identified: satisfaction, usefulness, tutors, evaluation and limitations.

- **Satisfaction:** Students are satisfied with the methodology and they perceive that PBL promote long-term retention of knowledge and acquisition of skills. “*This methodology is more effective than traditional learning because we consolidate in a better and deeper way knowledge”.*

- **Usefulness:** Students see PBL as useful for their future professions. Medical students emphasize more this aspect than human biology students. They start learning how research is performed and consider the skills learned important for their development. *"I think this kind of methodology is very positive and essential for our development as future professionals of health sciences"*.

- **Tutors:** Students identify the role of the tutor as relevant, they pointed out that there are different kinds of tutors and most of them consider the ideal tutor the one with previous experience in PBL who guides and acts as a facilitator. "*It would be nice that all the tutors had the same and concrete indications to guide in a proper way the sessions and avoid too directive tutors"*.

- **Evaluation:** Students perceived the evaluation in a positive way, although they noted that some criteria are subjective, and the tutor can influence the qualifications. "*I think that in some evaluations, some criteria are subjective and differs according to the tutor"*.

- **Limitations:** Students identify some limitations with the methodology, such as organisational issues, variability of tutors and small group issues. "*Small groups are suitable to perform PBL, however, sometimes we have tensions between us" or "Some tutors make less commentaries than other tutors. PBL is easier for the groups that have a tutor who gives more guidance*".

4. Discussion

This study examines the development of generic and research skills through the implementation of interdisciplinary PBL courses in the bachelors of Medicine and of Human Biology. Based on the assessment of a previous pilot experience (Carrió et al., 2011), these courses were designed to improve the development of generic and research skills, promote the students' creative thinking and increase the satisfaction with the methodology. For this reason, the implementation model shifted from a PBL-Module inside traditional subjects to full PBL-Courses.

Students' and tutors' perceptions on the development of generic and research skills were significantly enhanced in the PBL-Courses. This improvement can be attributed to the clarification of learning outcomes, skills-oriented evaluation and the role of the tutor as facilitator. In PBL-Courses, learning outcomes are clearly focused on generic and research skills, while in PBL-Module these skills could be blurred within the other learning outcomes from the traditional subjects. Consequently, assessment in PBL-Courses is skills-oriented and different tools, such as rubrics and observation grids, are used to foster metacognition and guide the skills development. The results suggest that students in PBL-Courses have better assimilated the intended learning goals and that assessment tools might have contributed to improve their skills development.

According to Chng et al. (2014), the tutor plays a role in facilitating student learning rather than only conveying knowledge, the tutor question, suggest and challenged the ideas raised by students (Chng et al., 2014). They have to make the transition from teacher as knowledge provider to tutor as a manager and learning facilitator (Savery, 2006b). This task demands a great amount of time and preparation and, as better the tutor know the students and the group interactions, better he/she can guide students' learning processes. In PBL-Courses, tutors lasted for the full 10 weeks course, instead of the PBL-Module, where tutors changed in every problem that was every 3 weeks. So, we partly attribute the improvement of the students' skills development in having long-time tutors, as they can better guide learning processes. In this study, students recognise the pivotal role of the tutor in their development, they consider that an ideal tutor has to facilitate and guide the learning processes as well as promoting creative thinking. Whenever the tutor had not maintained this role, it has been identified as a limitation of the PBL methodology.

So, our results suggest that students and tutors perceived having developed a high level of generic and research skills in PBL-Courses. Besides, the results show that exists a strong correlation between the development of generic and research skills. These results are also aligned with students' and tutors' comments.

Active learning and student-centred methodologies such as PBL imply that learners play an active role in planning, monitoring and evaluating the learning process. Thus, students have to consider different ways to approach a task, set clear goals, select strategies for achieving these goals, anticipate what has to be done and evaluate the process and the product of the learning cycle (Dolmans et al., 2005).

The generic and research skills development are intrinsically tied to this process. It is not surprising the strong correlation between the acquisitions of these two sets of skills. In fact, the ability to become a knowledge seeker, to be able to collaborate and communicate and to regulate and self-direct this learning process are essential skills to define a problem, analyse the situation and integrate and apply knowledge to develop solutions into new situations (Hmelo-Silver, 2004; Joham & Clarke, 2012; Murray-Harvey et al., 2005). Still, students and tutors think that this kind of methodology can also enhance creative thinking. It is a general consensus that domain-knowledge and skills are major components of creativity and that creativity occurs when investigating various aspects of a problem (L. Barrow, 2010; Hu et al., 2013). Scientific exploration and activities such as definition of scientific problems, hypothesis formulation, design of a research and evaluation of the evidences are considered key elements in scientific creativity development (Huang et al., 2017).

Furthermore, our hypothesis that cooperative work during the PBL learning process can enhance the development of generic and research skills has also been confirmed. The quantitative results show moderate correlations between the group dynamics and the development of generic and research skills. These results are also aligned with students' comments. The students consider that, during the learning process and the process of knowledge construction, working with peers make them analyse different perspectives, integrate different points of view and build on each other ideas to reach the solution of the problem presented. In fact, collaboration during the learning process involves mutual interaction and a shared understanding of a problem: participants have a common goal, share responsibilities and need to reach an agreement through mutual interaction. In this situation, learning and development of skills may be enhanced by elaborations, verbalisations, co-construction and cognitive and socially constructive criticism (Dolmans et al., 2005).

The PBL collaborative learning environment is also favourable to cultivate creativity. A high percentage of students (86%) thinks that they have been developed through these PBL-Courses. Based on the creative skills described by Burnett and Keller-Mathers (2017), we have found how these ones are developed during the PBL phases. In the first phase, students are encouraged to produce and consider many alternatives to solve the problem and afterwards they have to combine the different ideas and synthesise them in the working plan. In the second phase, students must share their research results and highlight the essence, keep open to new ideas or perspectives as possible solutions to the problem and elaborate their own answers. In the third phase, they use originality to present their findings and they put the new ideas into a bigger framework, the problematic situation. They also perform a self-evaluation about their participation in the group with which they become aware of their emotions, an aspect that have also been linked to creativity. Identifying how these skills are implicit in the PBL learning cycle can help the educators to emphasize in those and hence better promote the creative skills development.

On the other hand, students and tutors are more satisfied with the PBL-Courses than with the PBL-Module and they score much higher the usefulness of this pedagogical approach. Nonetheless, significant differences between the students of the different Bachelors have been found in PBL-Courses. Because satisfaction and usefulness show a strong correlation between them, the differences in these two items can be attributed to the perception that medical students find more useful the subject for their future professional lives than human biology students, as the applicability to the medical profession is very clear, and for human biology students is more diffuse, even though they develop essential skills for their future professions.

Students that performed the PBL-Courses stated that they were satisfied with this methodology because it allows them to develop useful skills, as the correlations between satisfaction and usefulness and generic and research skills also demonstrate. Also, they perceive that they retain the knowledge constructed for long-term. Thus, it is demonstrated that PBL promotes the development of generic, domain-specific, self-reflection skills and long term knowledge retention that would enable individuals to gain and apply new knowledge and skills as needed (Waldrop, 2015; Spronken-Smith &

Walker, 2010). These higher cognitive abilities such as problem-solving, collaboration or creative thinking will be demanded to confront new future and social challenges (Bosch & Casadevall, 2017; Justice, Rice, Roy, Hudspith, & Jenkins, 2009; M. Waldrop, 2015).

The increase of students' satisfaction in PBL-Courses could also be attributed to the recognition of the students' workload, which was identified as a critical aspect in the PBL-Module. In that model, students noted their dissatisfaction with the fact that the amount of workload was not rewarded enough in the final subjects' mark (Mar Carrió et al., 2018). This problem was solved in PBL-Courses, as the final marks were independent from traditional subjects. Students valued positively the different evaluative tasks and the only weakness they noticed was the role of the subjectivity in some cases. Students' perceptions of assessment are influenced by previous experiences; this means that any intervention involving assessment can be perceived in various ways by students, and thus can have effects on them and their learning process (Vaessen et al., 2017). So, in this case students' perceptions of assessment had to be considered in this subject to promote clarification to students concerns.

Our study has several limitations. The most important is related to its own characteristics. The aim of the study was exploring whether changing the PBL implementation model enhanced students learning outcomes and satisfaction with the learning experience. It was performed in a naturalistic academic environment and no experimental intervention was carried out. In this non-interventional design, many variables changed between the two models that were compared. Consequently, we cannot conclude which factors contributed most to enhance both aspects analysed, the perception of learning outcomes improvement and the satisfaction with the courses. Another limitation is the lack of evidence on the real students' development of generic, research and creative thinking skills by both models. This was not possible as the assessment methods used in those models were not comparable; therefore we focused the study in the students and tutors beliefs. However, we consider that our results as of interest as shows significant differences between both models and describe how these skills are developed from the students' and tutors perspective.

5. Conclusions

We conclude that the shift of implementation of PBL from PBL-Module integrated within traditional subjects to a full PBL-Courses only devoted to the use of this method has improved the students' perception on the improvement of generic and research skills development as well as their opinion on the educational value of this pedagogical approach and their satisfaction with their learning experience. It is important to outline that tutors also considered that PBL activities and learning experience, both satisfaction and usefulness. Even when this improvement was scored in both PBL implementation strategies, they also scored higher in PBL-Courses than in PBL-module. Correlation analyses showed the important relationship between the acquisition of generic and research skills and also between the perception of the usefulness of the PBL activities and the satisfaction with the experience. This is especially important as the students' satisfaction may enhance the students' engagement and, at the end, improves the learning. The study also showed how creative skills are worked in the different steps of PBL tutorials. We also hypothesise that the main educational settings in the PBL-Courses that contributed to this improvement has been the use of assessment tools better aligned with desired learning outcomes that encourage students in reflecting on their own learning processes together with maintaining the same tutor for all the course. Finally, the results of this study suggest that these PBL-Courses are a suitable pedagogical approach to develop generic, research and creative thinking skills, which have been identified as 21st century skills that must be taught and assessed in higher education (Geisinger, 2016).

Chapter 4. Developing creative and research skills through an open inquiry-based learning course: An interprofessional experience with undergraduate biomedical students

Rodríguez G, Pérez N, Núñez G, Baños JE, Carrió M.

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Chapter 5. Developing creative and research skills through an open Responsible Research and Innovation: an opportunity to develop creative skills at Higher Education

Rodríguez G, Saladie N, Revuelta G, Vizuete C, Llorente C, Carrió M.

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6. Discussion

6.1 Conceptualisation of creativity in biomedical research and its pedagogical implications in health sciences undergraduate education

One of the intial goals of this thesis was to investigate further how biomedical researchers described creativity in science, and to identify how, with their views and perspectives on this issue, creativity could be fostered in health sciences higher education. That is why we performed a study based on 15 semi-structured interviews with scientists from different Catalan biomedical research institutions. All interviewees were group leaders, and some of them were also university professors. They belonged to different biomedical research disciplines. The interviewed researchers were asked, firstly, about their own conceptualisation about scientific creativity and the attitudes and skills related to it; secondly, about the contextual environment in which scientific creativity can be developed, emphasising the importance of collaborative work, the influence of cultural and contextual environment and the influence of interdisciplinary research in science; thirdly, about scientific creativity in biomedical education, highlighting the strategies that can be used to foster scientific creativity in higher education and the proposals on creativity development in pedagogical practice; and finally, about potential creativity measuring tools in biomedical education.

Results obtained during this study suggest that researchers identify scientific creativity with the emergence of new, innovative, original and useful ideas, methodologies and ways to deal with a scientific problem through knowledge, discussion, structure of new conceptions and connections between interdisciplinary concepts. Furthermore, the researchers identified a set of skills essential for creative thinking, for which they highlighted inquiry, motivation, critical thinking, flexibility, openness, communication, multidisciplinarity and scepticism as crucial elements.

Besides, results of this study show that researchers define creativity as both an individual and a social skill, meaning that it can be enhanced through collaboration and interaction. Moreover, they claim that environment and cultural factors are also important in creativity development: open, free, interdisciplinary, innovative, and interprofessional environments, as well as national idiosyncrasy, media and politics, can directly affect the development of creativity.

Regarding the development of creativity in higher education institutions, researchers identified that pedagogical student-centred strategies promoting students' learning autonomy, as well as problem-solving skills, were essential to fostering creative thinking in science. Results of this study suggest that educational methodologies such as collaborative activities, Problem-Based Learning or Inquiry-Based Learning methodologies where scientific research processes and projects are developed, as well as the analysis of history of science scenarios, could be optimal creativity enhancers in higher education. Furthermore, researchers suggested that, if complemented with a tutor's guidance, these different approaches could be optimal to promote discussion, critical thinking, transversal and research skills, and consequently, scientific creativity. Besides, some researchers highlighted that creativity can be promoted with an integrated curriculum (a curriculum that eliminates discipline-based subjects and promotes learning through complex and multidisciplinary problems), and the rethinking of students' assessment including these creativity-related skills.

Finally, researchers state that comparison between products, design of creativity indicators and external specialist evaluation can be considered as pertinent measuring tools to evaluate if creativity is being developed during and as a result of the learning process.

Our results show that the interviewed researchers conceptualise creativity within a postmodern and socio-cultural approach. Thus, their perceptions support the view that creativity is seen as a social and collaborative phenomenon that implies interaction processes, and that is strongly influenced by the environment and its social and cultural properties (Raija Hämäläinen & Vähäsantanen, 2011; Plucker et al., 2004a; Sawyer, 2006). Researchers' socio-cultural view on creativity, together with the idea that it can be learned and enhanced, help us to connect the development of creativity within the socio-cultural perspective on learning. Therefore, since learning is regarded as a collaborative meaning-making process or as a construction by people in interaction, creativity and learning can be influenced by each other when groups of people are exploring new meanings (Chunfang Zhou, 2015). Thus, to the extent that it involves building a network of interrelated ideas, discovering or rediscovering concepts and principles, learning is a creative act itself. Therefore, as our results suggest, educators should: 1) provide tools for creativity that allow for students to learn how to capture and manipulate ideas, 2) encourage ways of thinking, perceiving and evaluating information that support creativity, and 3) help acquire a set of essential skills for creative thinking, which are well known to be better developed with student-centred methodologies (Richards, 1998).

Accordingly, these results can be considered as a first step in this thesis to rethink how to take a systematic approach to develop creativity, and in particular, to foster a creative learning environment by diverse strategies in biomedical education. Consequently, throughout this first step, we can identify which pedagogical methodologies are best fit for creativity development and, with them, design better approaches taking into account factors to promote creative skills in concrete scenarios.

6.2 Development of creativity through the inquiry process

After a first insight on how biomedical researchers conceptualise creativity and its pedagogical implications, different student-centred and inquiry models to promote creativity have been designed, implemented and assessed. One main goal of this thesis is to analyse how creativity has been developed through different pedagogical methodologies based on inquiry and collaborative work. So, different student-centred models have been implemented and assessed, from more structured, discipline-based inquiry models to more open and transversal approaches:

- Guided inquiry activities model through Flipped Classroom (Chapter 2, page 77).

- Problem-Based Learning model (Chapter 3, page 95).

- Interprofessional Project-Based Learning model (Chapter 4, page 119).
- Transdisciplinary Project-Based Learning model (Chapter 5, page 147).

Thus, we have analysed the following evidences to assess how creativity has been worked on in the different inquiry models. We have analysed, first, the students' perception on creativity development; second, the nexus between the development of transversal, research and creativity skills; third, the evidences on creativity development, and finally, the students' learning experience.

6.2.1 Students' perception on creativity development in different inquiry models

Regarding the students' perception on having developed creative thinking skills, some common points between the different models of inquiry can be found in our results. We have found that, in all the different models, students relate their perception on creativity development with the inquiry scenario as the starting point of the learning process. According to Abrandt and Öberg (2001), the intention of a scenario is that students associate it with real-life situations. This scenario provides a meaningful context to engage students in an active dialogue focusing on their learning process and, consequently, involving them in the creative process of knowledge construction (Abrandt Dahlgren & Öberg, 2001). That is why all the inquiry scenarios designed for this thesis were contextualised in real and social problems.

Despite the fact that the scenario has been identified as a crucial element for creativity development, different perceptions have been found among the different inquiry models. Our findings suggest that in a structured and subject-based inquiry model, where real-science and society scenarios are used, students perceive that they have been asked to think in a different way from traditional lectures. Therefore, they identify creativity with the debate on the social dimension of science. Moreover, students recognise that discussing about scientific issues that have an impact on society raises the awareness on how their future profession can affect people. This reflection leads to a more “democratic” view of science, which can mean starting a constructive dialogue between society and science (to establish more responsible scientific processes), and also including the environmental factors contextualised in the problem.

Besides, in the Problem-Based Learning model, the perception of creativity development through the inquiry scenario goes a little bit further. Our findings suggest that, in this kind of model, students associate creativity development with integrating, applying and combining knowledge from different fields of the same discipline (like PBL demands). Compared to the Guided inquiry activites model, students perceive that they have developed a more complex understanding of the problem, referring that they have made different connections between different biomedical disciplines, and that they have gone into deep discussions.

Regarding the open and interprofessional Project-Based Learning model, our results show that students have identified creativity development with the openness and flexibility of the inquiry scenario. They perceive that the freedom to choose a research topic fosters the generation of original and new ideas promoted by the integration of different fields and perspectives, especially in a concrete and current biomedical problem which can be approached from multiple perspectives. Students think that this openness leads to the development of creative ideas or projects.

Finally, regarding the open and transdisciplinary Project-Based Learning model, results describe that students perceive that a global, broad, relevant, shift paradigm scenario that emotionally involves participants promotes creativity development. This probably happens because the scenario tries to empathise with their daily lives and people can relate to them, but also because the scenarios can make people think about aspects they had not previously considered. This helps to enrich and develop ideas, and to consider a complex view of the environment.

Furthermore, our results show another common point among the different inquiry models regarding what students perceive as creativity enhancers. They identified learning processes that foster reflection and discussion as creativity stimulators. Our results show that students consider that peer discussion can foster the appearance of new ideas promoted by the integration and reorganisation of different points of view, perspectives, as well as the need to build solid arguments to reach the goal of the learning activity. These results resonate with the findings described by Craft (2005), and Zhou and Luo (2012): in collaborative and inquiry learning contexts, participants build on each other's ideas making new connections to reach a shared goal and an understanding that is not available at the beginning. Students share and evaluate well-grounded arguments and counter-arguments through collective discussion, and creativity helps to shape new opportunities of learning knowledge (Craft, 2005; C. Zhou & Luo, 2012). Moreover, our results also describe different students' conceptions on creativity development through discussion and peer interaction regarding the model of inquiry. Our findings suggest that students who have participated in open inquiry, such as the interprofessional Project-Based Learning and the transdisciplinary Project-Based Learning model, identify interprofessionalism and peers from different disciplines and fields of knowledge as an element that favours creativity development.

Finally, the last element identified by students as an enhancer for the development of creativity is the process of inquiry itself. This make sense because inquiry is not only defined by the traditional scientific method processes, but it also refers to the combining of these processes (which vary widely within and across disciplines and fields) with knowledge, reasoning, problem solving and critical thinking to develop scientific knowledge. So, inquiry is itself a creative act (Lederman et al., 2013). As the findings of this thesis show, the conception of the inquiry process as a creativity promoter varied through the different models regarding the aspects explained below.

So, our results show a difference of perspective regarding the level of guidance during the inquiry process, the openness of the inquiry, the focus of learning (which means the desired learning outcomes of the learning process), as well as the resulting product of inquiry. Students that participated in the Guided inquiry activities or the Problem-Based Learning models have highlighted as creative enhancers transversal skills and some higher cognitive abilities, such as the application of knowledge to other contexts, the analysis of complex problems or the development of critical thinking for example. This could be due to: 1) these models being highly scaffolded, or 2) the final outcome not being explicitly creative.

On the other hand, our results show that, in open inquiry models such as the interprofessional Project-Based Learning model and the transdisciplinary Project-Based Learning model, students are more aware of the need to use a set of different research and transversal skills to solve a complex situation, such as considering alternative solutions, making evidence-based choices, investigating different scenarios and exploring new questions through problem-solving and communication. Students identify all these elements as developers of their creativity. Furthermore, in these models, the resulting products are multidisciplinary research proposals assessed by an external expert committee. The outcomes obtained with these models are explicitly creative. We suggest that this combination of factors could raise the awareness of students about their creativity development. Our results on the different nature of inquiry models resonate with what Spronken-Smith and Walker (2010) explain: "as the level of scaffolding decreases, there is increasing choice regarding topic and method of study, an increasing capacity to do research, and consequently the ability to produce a perceptible creative product"(Spronken-Smith & Walker, 2010).

To sum up, we can state that students have perceived developing creativity in all four different models, through the identification of different creativity enhancers:

- The inquiry scenario: including a social dimension, multiple disciplines of knowledge and some elements to promote emotional implication to foster creativity development.

- Collaborative learning: discussions between peers and interactions between collaborators of different fields of knowledge have been identified as creativity enhancers.

- The inquiry process or the nature of inquiry: diminishing the level of scaffolding and guidance of the inquiry process has been identified as a promoter of creativity.

However, some differences on creativity development perception and awareness have been found, probably due to the fact that in open and interprofessional (or transversal) models, creativity is more explicit than in guided and disciplined-based models.

6.2.2 Relation between transversal and research skills and creativity development

Analysing the results of this thesis, we have found a nexus between transversal skills, research skills and creativity development. This nexus, analysed in depth in the Problem-Based Learning model and the Project-Based Learning model, is suggested by strong and significant correlations found between the perception of having developed transversal and research skills (r=0.62**) and between research skills and creativity development (r=0.64**), as well as supported by the qualitative data analysed in this thesis in the different inquiry models. Our qualitative data shows that, during inquiry processes, students perceive having developed a set of transversal skills (such as collaboration, communication, self-learning or metacognition) and different research skills (such as the definition of scientific problems, the design of an appropriate method of study, the evaluation of evidences and further construction of theories). In other words, they learn the capacity to do research. This happens in both guided and discipline-based models (such as Problem-Based Learning) and open and interdisciplinary models (such as Project-Based learning).

This data suggests and hypothesises that there exists a nexus between transversal skills, research skills and creativity development. This is proven not only by the strong correlations found between these variables and the perception of students, but also because during the inquiry process (in which the development of transversal and research skills is essential to reaching the learning goal), students also perceive having developed creativity, and in the two open Project-Based Learning models, having developed a creative product.

This nexus can be justified with the theoretical framework of creativity development. As Dolmans et al. explain (2005), during inquiry processes, learners play an active role in planning, monitoring and evaluating the learning process. Students have to consider different ways to approach a task, set clear goals, select strategies for achieving these goals, anticipate what has to be done and evaluate the process and the product of the learning cycle (Dolmans et al., 2005). Moreover, collaboration between peers involves communication, collaboration and a shared understanding of a problem: participants have a common goal, share responsibilities and need to reach an agreement through mutual interaction. In this situation, learning may be enhanced by elaborations, verbalisations, co-construction and cognitive and socially constructive criticism (Dolmans et al., 2005). So, the development of generic and research skills are intrinsically tied to the ability to become a knowledge seeker, to be able to collaborate and communicate and to regulate and self-direct this learning process. Therefore, these are essential skills to define and analyse a problem, and integrate and apply knowledge to develop solutions into new and complex situations (Hmelo-Silver, Duncan, & Chinn, 2007; Joham & Clarke, 2012; Murray-Harvey et al., 2005).

This has a lot to do with the socio-cultural approach of creativity development, where creativity is understood as a way of expanding what one knows and of understanding what one can reach (Craft, 2005). In fact, during the learning process, when students learn something new, they are making new connections between ideas and making sense of them for their selves. They are constructing knowledge and, in this sense, we can describe what they are doing as being creative (Craft, 2005). Creative thought is not just a matter of idea generation, but it also involves identifying and defining problems, questioning and challenging, making connections and conceptual combination, exploring ideas, keeping options open, problem-finding, information search and evaluation, and reflecting critically on ideas, actions and outcomes (Craft, 2005; Scott et al., 2004b). Thus, creativity offers the opportunity to shape new knowledge, something that cannot occur without some understanding of what already exists, and without opportunities to engage with it. Transversal and research skills, therefore, become essential in the process of creative learning by using imagination and experience, strategic collaboration, and critically evaluating one's own learning.

6.2.3 Evidences of creativity development in the different inquiry models

Evidences of creativity development are not just based on the students' perception, despite involved individuals' voices have been considered as focus of documentation in educational and recent creativity research (Craft, 2005). Evidences on creativity development found on the four models of inquiry assessed have been collected and evaluated. It is not easy to prove the development of creative thinking, so different perspectives have been taken into account (in the different inquiry models) to find these evidences.

In all the different inquiry models studied in this thesis, evidences on creativity development have been analysed through an adaptation of the theoretical framework "*Integrating creative thinking skills into the Higher Education classroom*" (Burnett & Keller-Mathers, 2017). This framework has been used to evaluate which different set of skills that shape creative thinking have been developed.

In the case of the Guided inquiry activities model, the activities were assessed within this theoretical framework. We have found that students were able to define and analyse problems, generate original and different ideas, explore different options, include different points of view into complex situations, produce robust arguments while elaborating on each others' contributions, and communicate complex arguments while highlighting the main ideas. Therefore, considering the skills the students acquired, we conclude that the activities of this inquiry model enhanced the development of creativity.

In the case of the Problem-Based Learning model, we have also used this theoretical framework to analyse the phases during the PBL learning process and students' comments. Our findings show that students become able to define complex problems, produce and consider many alternatives from different fields, combine and connect different ideas, elaborate and develop these ideas while keeping an open mind to and considering peers' perspectives, highlight the essence of these ideas, being aware of each ones' feelings thorugh communication and collaboration, and finally putting them into a bigger framework, that is, a complex problem. This set of abilities developed during the PBL learning process is evidence of creativity development.

For the both open and multidisciplinary Project-Based Learning models, in which students are asked to elaborate a creative product, we have analysed the characteristics of these products. In these two cases, we used Hu and Adey's model considering the product developed (technical product, advance in science knowledge, understanding of scientific phenomena, and scientific problem solving) and the creative trait (which consists of 1) *originality*, defined as an answer that is rare occurring occasionally in a given population, 2) *value*, defined as the importance in a given context, and 3) *usefulness*, defined as the aptitude to satisfy a need) (Hu & Adey, 2002; Plucker et al., 2004a). We have found high rates of creativity (from 7.1 to 8.4 in the interprofessional Project-Based Learning model and from 7.7 to 8.7 in the transdisciplinary Project-Based Learning model), as well as different scientific products (36% advances in science knowledge, 25% science problem solving, 21% understanding science phenomena and 18% technical products).

Furthermore, in these two models we have also analysed the set of creativity skills developed during the learning process. The results show first, a deeper development of some of the creativity skills developed in the two previous models, and second, the development of new creativity skills such as describing the inside and internal dynamics of all processes occurring during the students' projects, changing the paradigm and thinking-outside-the-box of the given requirements, reflecting about how these projects can have a future impact and presenting the projects in a different and visual way. Finally, in the transdisciplinary Project-Based Learning model, participants use fantasy, imagination and the non-existent to produce a transdisciplinary project.

Scientific creativity can be assessed by the process, the product and the creative trait, so the development of creative skills is demonstrated in the productions' and the process analysis. On one hand, students have developed different scientific products that find creative solutions to scientific problems; and on the other hand, the traits that define creativity can be identified, with high scores, in students' productions. Furthermore, the set of creativity skills developed during the process has also been identified.

6.2.4 Students' learning experience in different inquiry models

Our results show that the four different inquiry models have obtained high scores of satisfaction. Regarding the Guided inquiry activities model, our findings suggest that the structured-inquiry activities demanded an active role on students' behalf which traditional lectures did not. Notably, students felt more involved in classes and were highly motivated and willing to participate in discussions. They explained that they learned more easily with these activities, that it was easier for them to fix knowledge (by applying what they learned and by reflecting on it), and that they kept the constructed knowledge over a long period.

Something similar has been found in the Problem-Based Learning model, where this inquiry process allowed students to develop useful transversal and research skills such as problem solving, collaboration, or self-learning. In this case, they also perceived that they retained the knowledge constructed for a long period of time. In the PBL model, results also show that students highlight the tutors' task as facilitators as an important factor during their learning experience.

In the case of the interprofessional Project-Based Learning model, our results suggest that students were satisfied with their projects and with the inquiry approach, and they highlighted that it allowed them to learn new and useful skills for their academic activities and their future professions. They also pointed out that the knowledge acquired was retained. Tutors played an important role and were also regarded as an important factor in the students' learning experience. Students considered that the ideal tutor should have experience as a facilitator, should act as a guide (not just as an evaluative figure), and should find the balance between promoting a free environment and directing discussions when needed in order to enhance creativity. Students considered that positive emotions helped them develop better projects and be more involved in the inquiry process.

In the transdisciplinary Project-Based Learning model, our results suggest that the main elements of satisfaction of the learning experience were the kind of inquiry model, the topic or inquiry scenario, the activities performed during the inquiry process and the facilitators.

All in all, these results can provide with an understanding on how the learning experience in the different inquiry models can define the satisfaction of each methodology. These results constitute another argument to support creative training because, as our results show, the development of creativity and satisfaction are strongly correlated (r= 0.612**). Besides this, all factors involved in students' satisfaction regarding the inquiry process can be identified as elements of creativity development and also improve creativity in the different inquiry approaches.

6.3 Creativity and inquiry conceptual model

As explained above, an adaptation of the theoretical framework on "*Integrating creative thinking skills into the Higher Education classroom*" has been used to evidence the development of creativity in all the different inquiry models (Burnett & Keller-Mathers, 2017). The evaluation of the set of skills that shape creative thinking has been made through the analysis of students' comments and the field notes taken during the inquiry learning process of each model. Table 1 shows a summary of the creativity skills developed in each inquiry model.

Table 1. Creative thinking skills development in four different inquiry models: Guided inquiry (GI), Problem-Based Learning (PBL), Interprofessional Project-Based Learning (I-PjBL) and Transdisciplinary Project-Based Learning (T-PjBL).

	GI	**PBL**	**I-PjBL**	**T-PjBL**
Problem-solving	X	X	X	X
Produce and consider many alternatives	X	X	X	X
Societal	X	X	X	X
Be flexible	X	X	X	X
Be original	X	X	X	X
Highlight the essence	X	X	X	X
Elaborate but not excessively	X	X	X	X
Keep an open mind	X	X	X	X
Be aware of emotions		X	X	X
Put ideas into context	X	X	X	X
Combine and synthesise		X	X	X
Visualise it			X	X
Use fantasy				X
Look it another way	X	X	X	X
Visualise the inside			X	X
Expand the boundaries			X	X
Get glimpses of the future			X	X

The results of this table show that in all models students developed a high number of creative thinking skills.

Some of these skills are developed in the four inquiry models. In all them, students have to define a complex problem or situation. They also have to look for and come up with different solutions for the problem, considering societal issues as well as producing original ideas from different fields of knowledge. Furthermore, during these inquiry models, students also have to highlight the essence of what they are working on so that they can properly communicate ideas to peers. In the process of collaboration, students have to keep an open mind and integrate all different points of view and perspectives, elaborate arguments on their discussions and integrating all of them in a bigger framework, the complex problem.

Other creative thinking skills are solely developed in the Problem-Based Learning model, the interprofessional Project-Based Learning model and the transdisciplinary Project-Based Learning model. These skills are related to 1) combining and synthesising information discussed during the inquiry sessions in the aim of reaching the learning outcomes proposed by each model, and 2) being aware of the emotions of all collaborators to promote an optimal learning experience.

Other creativity skills are connected to the two Project-Based Learning inquiry models. As explained above, these skills are related to 1) visualising the inside, 2) expanding the boundaries, 3) reflecting about future issues and 4) presenting the projects in a visual way. Moreover, in the transdisciplinary Project-Based Learning model, participants use imagination to elaborate the project.

These results show that all inquiry models develop creative thinking skills, and that some of these skills are common between the four models. The analysis of the students' comments and the field notes of the inquiry learning process of each model suggest that these skills are highly developed in more open inquiry models (such as the interprofessional and transdisciplinary Project-Based Learning). So, the results confirm that creative thinking skills are developed the most in models that are less guided and more transdisciplinary.

With the results obtained in 1) our studies, 2) the analysis of the creative thinking skills in each inquiry model (section 6.2.3 and Table 1), and 3) by going deeply into the extensive literature of creativity, we have designed a creativity and inquiry conceptual model. This model is based on our findings and our understanding of creativity, learning and inquiry. Figure 1 shows the conceptual model of linkages between creativity development and the nature of inquiry, defined by 1) the inquiry scaffolding, 2) the content or disciplines involved during the inquiry process (subject-based, discipline-based, interprofessional and transdisciplinary) and the focus of inquiry (that is, what students are expected to do during the learning process) and 3) the skills developed (transversal and research skills).

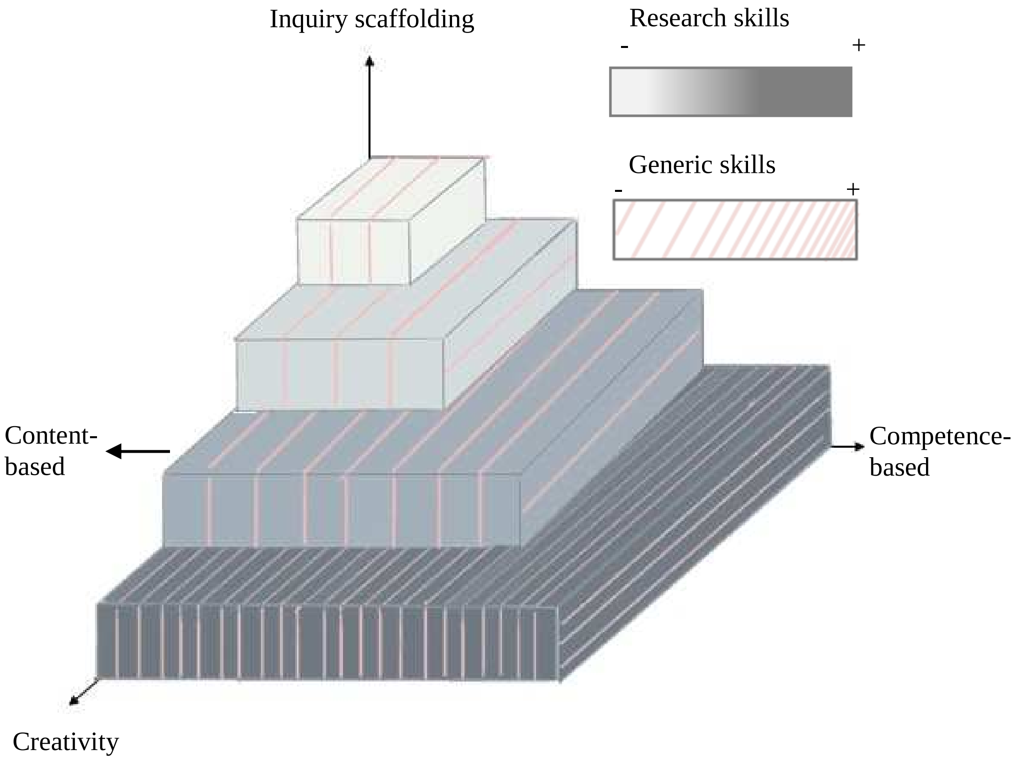

Figure 1. Conceptual model showing the relationship between the nature of different models of inquiry and creativity development.

This model shows that the nature of inquiry plays a role in creativity development. Inquiry models with 1) higher levels of scaffolding, 2) subject-based or discipline-based, and 3) a focus of learning based on finding the existing answer to a tutor-proposed question in a determinate subject (Guided inquiry activities model), or to the students-proposed question in a discipline (Problem-Based Learning model), are linked to lower levels of creativity. Furthermore, in these two models, transversal and research skills are developed more superficially. This fact can also be related to lower levels of creativity development.

On the contrary, interprofessional or transdisciplinary inquiry models with 1) lower levels of scaffolding and 2) a focus of learning based on research on how students can answer their own question in interdisciplinary environments (interprofessional Project-Based Learning model and transdisciplinary Project-Based Learning model) are linked to higher levels of creativity development. Besides, these two models require the development of research skills and consolidated transversal skills. This fact can also be related to higher levels of creativity development.

6.4 Key elements to develop creativity in undergraduate biomedical studies

6.4.1 Complexity and uncertainty

As explained above, having to deal with a problem has been identified as one of the main enhancers of creative thinking. During the implementation of the four inquiry models, different problems have been designed and used. Depending on the level of scaffolding and the model of inquiry, problems were designed considering subject-based scenarios, discipline-based scenarios, interdisciplinary scenarios and finally, transversal scenarios.

All problems designed for this thesis considered complexity and uncertainty in order to foster creativity. Complexity refers to many components being involved in a problem (and these components influencing one another through links of different strengths), while uncertainty means that not all requirements are known and not all criteria are established (Zhou, 2017). These two characteristics were considered in this thesis when framing creative problems. Furthermore, different components involved in complexity and uncertainty have been identified as essential factors in complex and creative problem design (Thomé, Scavarda, Scavarda, & Thomé, 2016). Our results provided enough evidence on the development of creativity in undergraduate biomedical students, and thus, we describe the components used to design and frame the problems in our context as possible enhancers of creativity:

- Including information from different disciplines, sources of insights and points of view can favour the development of creativity.

- Problems that incorporate a social perspective and the environment where they are set can enhance creativity.

- Designing a problem that does not have a unique goal and in which the information delivered is not explicit can contribute to train creative thinking.

- Problems that promote processes of questioning and investigation to reach a desired goal are related to creativity development.

- Problems that present a complex situation that can be solved in different ways can also be considered creativity enhancers.

- Flexible and open problems that allow changes during the process of solving them also contribute to creative training.

- Problems that promote different types of products as solutions can have an impact on creativity development.

- Complex problems (seen as learning opportunities) that involve a learning process are key to foster creativity development.

6.4.2 Collaborative work

Collaborative work has been identified in our results as an essential element in creativity development and training. As Chin and Osborne (2008) explain, discussion and debate between peers about shared problems or tasks can enhance group members to use relevant thinking strategies and processes in the search for an answer. Discussions and debates promote alternative viewpoints that stimulate students to consider the pros and cons of different perspectives of an issue and fosters the process of argumentation, critical thinking and, consequently creative thinking (Chin & Osborne, 2008).

What we have seen in our results, and is also documented in the literature on collaborative work, is that collaborators are not a group of homogenous people, but rather individuals with different perspectives, expertise, conceptualizations, working methods, temperaments, resources, needs, and talents (Zhou, 2015). So, to design different learning methodologies for creative thinking, collaborators and collaboration essential elements must be identified and taken into account. With our results, we have identified crucial collaboration aspects in creative training:

- Collaborative activities that have enough space and time to discuss, share information, promote collaborative reasoning and voting have been identified as creativity enhancers.

- Collaboration that leads to ideas, decisions and plans is key for creativity development.

- Big groups can experience difficulties reaching creativity development (as they tend to obviate some members' ideas); and small group can experience difficulties reaching the desired goal. When working with small groups in collaborative activities, 5 to 8 people have been identified as an optimal size.

- Members from different fields and backgrounds can enhance creativity development due to a higher number of perspectives, points of view, arguments, ideas and methodologies.

- Assigning individual roles focused in a specific task can contribute to students' emotional stability. Students don't feel overwhelmed by the learning experience, and this fact, in a collaborative process, can improve knowledge construction and facilitate creativity development.

- A collaborative process facilitated by a tutor who 1) takes into account individual skills, 2) fosters an affective relationship between members, and 3) highlights the outputs of the collaborative process (such as the ideas, solutions or preferences to reach a successful collaboration), facilitates the creative process of knowledge construction.

6.4.3 Cognitive abilities that foster creativity

Techniques that promote different cognitive abilities in interactive and collaborative environments can be used as an optimal tool in creativity development. As Adams et al. (2008) explain, including some stimulatory techniques fostering different creativity thinking skills in group sessions (such as brainstorming or mind mapping) can be enhancers in creative thinking training (Adams et al., 2009a).

In our studies we have found that introducing stimulatory techniques (in a four-hour workshop) in the open and interprofessional Project-Based Learning inquiry model improves 1) idea generation and evaluation, 2) different ways of thinking and perceiving information, and 3) group cohesion. Different techniques were used to improve various cognitive abilities related to creativity development and training. The introduction of stimulatory techniques in this inquiry model has not had any effects on the usefulness and satisfaction with the learning model, but has had a positive effect on students' perception of creativity development and learning results.

Here we describe, after having analysed our results, elements that we consider important to take into account in the introduction of stimulatory techniques to train creativity:

- Students' preconceptions about creativity should be arisen. It is recommendable to introduce and construct a common creativity theoretical framework before starting with stimulatory techniques.

- To properly train creativity, enough time should be dedicated to each stimulatory technique.

- Small groups (6-8 people) are the optimal size to work with stimulatory techniques and train creativity.

- Different techniques can be used to promote idea generation and different ways of thinking: brainstorming, heuristics ideation (identification of unexpected connections between different fields), role storming (different perspectives on an issue), or de Bono's Six Thinking Hats (parallel and creative thinking in groups).

- Some techniques can also be used in the evaluation of ideas, such as the strange object (use of analogies), the Ishikawa diagram and the SWOT (different approaches to problem solving), the SCAMPER technique (further development of ideas), and the Logo design (use of imagery to represent a complex element).

- A safe, relaxed, open, collaborative and guided environment has been identified as a creativity enhancer.

Stimulatory techniques have been used in a specific workshop destined to train creativity. After the analysis of the usefulness of these techniques on project development, we suggest that they can also be used in PjBL tutorial sessions. However, our results show that a working and guided environment, without the presence of tutor, generates a more relaxed and safer space.

6.4.4 Indicators for the design of inquiry activities to train creativity

One of the main goals of this thesis is to propose some indicators for the design of activities destined to the training of creativity and its assessment, as creativity assessment has always been a complicated and an unresolved issue. For this reason, here we propose 1) a list of indicators to introduce creativity in learning processes based on student-centred inquiry approaches (fostering transversal and research skills), Table 2 shows a list of indicators to design inquiry activities that promote creativity development.

Table 2. Indicators to design inquiry activities for creativity development. The list of indicators is based on four different aspects: 1) the problem 2) collaborative work, 3) the guided inquiry process and 4) the introduction of stimulatory techniques.

	Indicators
The problem	-Includes multidisciplinarity and different sources of insights. -Includes a social perspective and environment elements. -Empathizes with the students or arouses emotions -Avoids explicitness. - Challenge the students -Uses inquiry as the starting point, it stimulates different questions. -Allows multiple solutions that can be presented in different ways and as different products. -Enable flexibility, it allows a degree of change during problem-solving. -The problem analysis involves a learning process.
Collaborative work	-Promotes interaction, discussion and reflection between peers. -Leads to a group response: ideas, decisions and plans. -Considers the ideal group size (between 6 and 8 people). -Generates heterogeneous groups: students with different motivations, academic profiles, personal traits, disciplines, etc. - Favours to analyse the problem from different perspectives -Assign individual roles.
The guided inquiry process	-The tutors should be trained in inquiry approaches. - Should be facilitated by a tutor, through questioning and not directive instructions. -The tutor should consider individual skills, affective relations and highlight outputs of the collaborative process. -The tutor promotes a safe and relaxed inquiry environment. - Recognises the generation of different ideas and perspectives and highlight the original ones - Fosters the students to develop their ideas through elaborations - Stimulates the students to bridge new connections and keep an open mind - Explore possibilities that do not exist
Stimulatory techniques	-Include activities to emerge students' preconceptions about creativity and construct a common theoretical framework.

	-Less is more: introduce a small number of techniques and dedicate more time to each of them. -Use small groups (6-8 people). -Use techniques to promote idea generation and idea evaluation. -Use techniques in workshops or tutorial sessions. -Promote a distended and relaxed environment.

6.4.5 Introducing the creativity and inquiry conceptual model into biomedical undergraduate education

The main goal of creative training is that students attain the highest level of creativity development through inquiry processes. One interpretation of this model suggests that guided and subject-based or discipline-based inquiry approaches should precede open and transversal inquiry models. This way, creative training can be enhanced and developed if the level of scaffolding is decreased throughout the students training process, and the number of disciplines involved in the learning process is increased.

As we have seen before, it is essential to possess a set of transversal and research skills to be able to develop creative thinking. Therefore, it is better to train first-year students within a more guided, subject-based and discipline-based inquiry models so that they can develop transversal skills and research skills little by little. They can be introduced to creative thinking training by including some creative elements in the learning process. As they gain expertise, students can progress to inquiry models that allow lower levels of scaffolding and more trasndisciplinarity. Within these models, research skills are more developed and consolidated, and transversal skills are already constituted. Creative thinking is further improved by the consolidation of the needed skills in a progressive way.

6.5 Limitations

This thesis has obtained promising results regarding creativity training and development through different inquiry models. However, some limitations have also been found. Firstly, this study is centred in a specific context with specific students. This means, that the results obtained during this four-year work are also tied to our Faculty context and to our students' profile; in other words, to a determinate environment. Although we think that the described strategies to promote creativity development are translatable to other contexts and other students, these two facts should be taken into account, an adapt creativity training, if needed, in each specific scenario. Secondly, another limitation of this thesis falls on the results, which are restricted to few participants on a single university. Finally, this study focus basically on students' perception, students' learning results, students' productions and researchers' observations. It would be ideal to introduce all the involved and affected actors in this study. This means including the tutors' and professors' voices in all the four inquiry models, for example, or including ex-students' perspectives.

7. Conclusions and future implications

7.1 Conclusions

Regarding the conceptualisation of creativity of scientists from Catalan research institutions:

- The scientists conceptualise creativity as the relation between abilities, attitudes and contextual and social factors.

- The scientists identified pedagogical student-centred strategies, such as collaborative activities, Problem-Based Learning or Inquiry-Based Learning, as optimal methodologies to train creativity.

- The scientists proposed curriculums based on complex and multidisciplinary problems, as well as a new paradigm of students' assessment as essential facts to train creativity in higher education.

Regarding the Guided inquiry activities model:

- Students are highly satisfied with this inquiry model.

- The students perceive having develop critical thinking and creativity with the guided inquiry activities model.

- Students perceive learning more easily with this inquiry model. In fact, the students obtain better results with this model than in traditional lectures.

Regarding the Problem-Based Learning model:

- A PBL model based on full PBL courses instead of PBL activities inside traditional subjects have obtained better results regarding to generic and research skills development, satisfaction and usefulness.

- The students are highly satisfied with this inquiry model.

- The students perceive having developed, in a high level, transversal and research skills.

- There is a strong correlation between the development of transversal and research skills in the PBL model.

- The development of transversal and research skills is related to high levels of satisfaction with the methodology.

- The students perceive having develop creative thinking skills with this inquiry model. How these skills are developed during different PBL phases have been identified.

- The tutors think that with this PBL model the students develop transversal, research and creative thinking skills. They also are highly satisfied with the teaching experience and consider this pedagogical approach very useful.

Regarding the Interprofessional Project-Based Learning model:

- The students perceive having acquired research and creative skills.

- Research skills and creativity are dependent between them.

- The introduction of stimulatory techniques in this inquiry model has improved the students learning outcomes and their perception of creativity development.

- Students are highly satisfied with this inquiry model and perceive it as useful for their future profession. They also highlight the interest of working in interprofessional teams due to the opportunity to discuss a complex problem from different perspectives.

- There is a relation between the development of transversal and creativity skills and the satisfaction with the inquiry model.

Regarding the Transdisciplinary Project-Based Learning model:

- The students perceive having developed creativity with this inquiry model. The students consider that the designed projects are creative.

- The students think that the use of a transdisciplinary problem, as the point of departure in the inquiry process, stimulates them to create original projects.

- The students think that a theoretical framework based on responsibility in research processes contributes to the development of creative projects.

- The students are highly satisfied with this inquiry model.

General conclusions:

- The students are highly satisfied with the four inquiry models.

- The students perceive having develop creativity in the four inquiry models tested in this thesis.

- Training in creativity influences positively students' satisfaction with the learning process and the inquiry model.

- In open and multidisciplinary inquiry models more elements that promote creative skills have been identified compared to guided inquiry models.

7.2 Future impacts

The urgent need for trained and innovative professionals who can face the challenges of the approaching decades supports the idea of training creativity in higher education. The findings of this thesis open the door to consider creativity as an essential skill in biomedical education. The results of this study suggest that creativity development through inquiry has a positive impact in the students' learning experience. So, in a general view, emphasise the idea that there should be a change in the way we educate our future generations. Furthermore, student-centred strategies based on inquiry, which foster 21st skills development, should be introduced in higher education as the main pedagogical approach. Although creativity training has always been a difficult issue to treat, this thesis, in a more specific view, gives enough evidences and indications to design collaborative and inquiry activities that foster creativity development. So, the main contributions of this study are the guidelines to introduce this skill, using different strategies, in the curriculum. This thesis does a bit to help the start of a substantial change in individuals' learning and education.

8. Bibliography

Abrandt Dahlgren, M., & Öberg, G. (2001). Questioning to learn and learning to question: Structure and function of problem-based learning scenarios in environmental science education. *Higher Education*, *41*(3), 263–282. https://doi.org/10.1023/A:1004138810465

Adams, D. J., Beniston, L. J., & Childs, P. R. N. (2009a). Promoting creativity and innovation in biotechnology. *Trends in Biotechnology*, *27*(8), 445–447. https://doi.org/10.1016/j.tibtech.2009.05.001

Alhadeff-Jones, M. (2010). Challenging the Limits of Critique in Education Through Morin's Paradigm of Complexity. *Studies in Philosophy and Education*, *29*(5), 477–490. https://doi.org/10.1007/s11217-010-9193-8

Althusser, L. (1971). Ideology and the State. In *Lenin and Philosophy and Other Essays*.

Amabile, T. M. (1996). *Creativity in context*. *Boulder*. https://doi.org/10.1146/annurev.psych.093008.100416

Barrow, L. (2010). Encouraging Creativity with Scientific Inquiry. *Creative Education*, *1*, 1–6.

Barrow, L. H. (2006). A brief history of inquiry: From dewey to standards. *Journal of Science Teacher Education*, *17*(3), 265–278. https://doi.org/10.1007/s10972-006-9008-5

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*. https://doi.org/10.1002/tl.37219966804

Baum, B. J. (2003). Can biomedical science be made relevant in dental education? A North American perspective. *European Journal of Dental Education : Official Journal of the Association for Dental Education in Europe*.

Becker, H. S. (1990). Art Worlds revisited. *Sociological Forum*. https://doi.org/10.1007/BF01115099

Beghetto, R. A., Kaufman, J. C., Hegarty, C. B., Hammond, H. L., & Wilcox-Herzog, A. (2012). Cultivating creativity in early childhood education: A 4 C perspective. *Contemporary Perspectives on Research in Creativity in Early Childhood Education.* Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=psyc9&NEWS=N&AN=2012-13642-012

Beghetto, R., & Kaufman, J. (2013). Fundamentals of creativity. *Educational Leadership*, *70*(5), 10–15.

Bosch, G., & Casadevall, A. (2017). Graduate biomedical science education needs a new philosophy. *MBio*, *8*(6), 25–29. https://doi.org/10.1128/mBio.01539-17

Breslin, D. (2017). Studies in Higher Education Group creativity and the time of the day Group creativity and the time of the day. *Studies in Higher Education*, *0*(0), 1–16. https://doi.org/10.1080/03075079.2017.1413082

Burnett C., Keller-Mathers S. (2017). Integrating Creative Thinking Skills into Higher Education. In: Zhou C, editor. *Creative Problem-Solving Skill Development in Higher Education*. 1st ed. Hershey (PA): IGI Global. p. 283-304.

Cantillon-Murphy, P., McSweeney, J., Burgoyne, L., O’Tuathaigh, C., & O’Flynn, S. (2015). Addressing biomedical problems through interdisciplinary learning: A feasibility study. *International Journal of Engineering Education*.

Carrió, M., Agell, L., Banõs, J. E., Moyano, E., Larramona, P., & Pérez, J. (2016). Benefits of using a hybrid problem-based learning curriculum to improve long-term learning acquisition in undergraduate biology education. *FEMS Microbiology Letters*, *363*(15), 1–7. https://doi.org/10.1093/femsle/fnw159

Carrió, M., Agell, L., Rodríguez, G., Larramona, P., Pérez, J., & Baños, J. E. (2018). Percepciones de estudiantes y docentes sobre la implementación del aprendizaje basado en problemas como método docente, *21*(3), 143–152.

Carrió, M., Larramona, P., Baños, J. E., & Pérez, J. (2011). The effectiveness of the hybrid problem-based learning approach in the teaching of biology: A comparison with lecture-based learning. *Journal of Biological Education*, *45*(4), 229–235. https://doi.org/10.1080/00219266.2010.546011

Chen, C.-K., Jiang, B. C., & Hsu, K.-Y. (2005). An empirical study of industrial engineering and management curriculum reform in fostering students' creativity. *European Journal of Engineering Education*, *30*(2), 191–202. https://doi.org/10.1080/03043790500087423

Chen, F., Lui, A. M., & Martinelli, S. M. (2017). A systematic review of the effectiveness of flipped classrooms in medical education. *Medical Education*. https://doi.org/10.1111/medu.13272

Chi Hong Nguyen. (2010). The Changing Postmodern University. *International Education Studies*, *3*(3), 88–99. Retrieved from http://search.ebscohost.com.ezproxy.liv.ac.uk/login.aspx?direct=true&db=ehh&AN=52739808&site=eds-lve&scope=site&scope=cite

Chin, C., & Osborne, J. (2008). Students' questions: a potential resource for teaching and learning science. *Studies in Science Education*, *44*(1), 1–39. https://doi.org/10.1080/03057260701828101

Chng, E., Yew, E. H. J., & Schmidt, H. G. (2014). To whatextent do tutor-related behaviours influence student learning in PBL? *Advances in Health Sciences Education*. https://doi.org/10.1007/s10459-014-9503-y

Chowning, J. T., Griswold, J. C., Kovarik, D. N., & Collins, L. J. (2012). Fostering critical thinking, reasoning, and argumentation skills through bioethics education. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0036791

Connolly, P. (2007). *Quantitative data analysis in education : a critical introduction using SPSS*. Routledge.

Craft, A. (2005). *Creativity in schools: Tensions and dilemmas*. *Creativity in Schools: Tensions and Dilemmas*. https://doi.org/10.4324/9780203357965

Cvijovic, M., Höfer, T., Aćimović, J., Alberghina, L., Almaas, E., Besozzi, D., … Hohmann, S. (2016). Strategies for structuring interdisciplinary education in Systems Biology: an European perspective. *Npj Systems Biology and Applications*. https://doi.org/10.1038/npjsba.2016.11

Daud, A. M., Omar, J., Turiman, P., & Osman, K. (2012). Creativity in Science Education. *Procedia- Social and Behavioural Sciences*, *59*, 467–474. https://doi.org/10.1016/j.sbspro.2012.09.302

Dehaan, R. L. (2009). Teaching Creativity and Inventive Problem Solving in Science. *CBE-Life Sciences EducationLife Sciences Education*, *8*, 172–181. https://doi.org/10.1187/cbe.08

Delany, C., & Watkin, D. (2009). A study of critical reflection in health professional education: “Learning where others are coming from.” *Advances in Health Sciences Education*, *14*(3), 411–429. https://doi.org/10.1007/s10459-008-9128-0

Derting, T. L., & Ebert-May, D. (2010). Learner-Centered Inquiry in Undergraduate Biology: Positive Relationships with Long-Term Student Achievement Terry. *Cell Biology Education*, *9*, 462–472. https://doi.org/10.1187/cbe.10

Dewey, J. (1916). *Democracy and Education: An Introduction to the Philosophy of Education. Textbook series in education*. https://doi.org/10.2307/992653

Dewey, J. (1938). Experience and Education. *Education*. https://doi.org/10.1017/CBO9781107415324.004

Dolmans, D. H. J. M., De Grave, W., Wolfhagen, I. H. A. P., & Van Der Vleuten, C. P. M. (2005). Problem-based learning: Future challenges for educational practice and research. *Medical Education*, *39*(7), 732–741. https://doi.org/10.1111/j.1365-2929.2005.02205.x

Downing, K., Kwong, T., Chan, S.-W., Lam, T.-F., & Downing, W.-K. (2009). Problem-based learning and the development of metacognition. *Higher Education*, *57*(5), 609–621. https://doi.org/10.1007/s10734-008-9165-x

Edgren, G. (2006). Developing a competence-based core curriculum in biomedical laboratory science: A Delphi study. *Medical Teacher*. https://doi.org/10.1080/01421590600711146

Elo, S., Kääriäinen, M., Kanste, O., Pölkki, T., Utriainen, K., & Kyngäs, H. (2014). Qualitative Content Analysis. *SAGE Open*, *4*(1), 215824401452263. https://doi.org/10.1177/2158244014522633

Esparza, J., & Yamada, T. (2007). The discovery value of "Big Science." *The Journal of Experimental Medicine*, *204*(4), 701–704. https://doi.org/10.1084/jem.20070073

Epstein LH. (2013) Creative Scientist Workshop Fosters Biomedical Science Innovation [Internet]. Buffalo (NY): University of Buffalo, Jacobs School of Medicine and Biomedical Sciences; 2013 May 15 [updated 2018 Jan; cited 2018 Feb 15]. Available from: http://medicine.buffalo.edu/news_and_events/news.host.html/content/shared/smbs/news/2013/05/creative-scientist-workshop-innovative-2208.detail.html

Eun, B. (2017). The zone of proximal development as an overarching concept: A framework for synthesizing Vygotsky's theories. *Educational Philosophy and Theory*, *1857*, 1–13. https://doi.org/10.1080/00131857.2017.1421941

Friedman, D. B., Crews, T. B., Caicedo, J. M., Besley, J. C., Weinberg, J., & Freeman, M. L. (2010). An exploration into inquiry-based learning by a multidisciplinary group of higher education faculty. *Higher Education*, *59*(6), 765–783. https://doi.org/10.1007/s10734-009-9279-9

García-García, M. J., González-García, C., Fernández, L. J., Casado-Sánchez, J.-L., Muneta, L. M., Jesus Garcia-Garcia, M., Martinez Muneta, L. (2015). Assessing Creativity in Engineering Students: A Comparative Between Degrees and Students in First and Last Year. *International Journal of Engineering Education*.

Geisinger, K. F. (2016). 21st Century Skills: What Are They and How Do We Assess Them? *Applied Measurement in Education*, *29*(4), 245–249. https://doi.org/10.1080/08957347.2016.1209207

Gibbons, M. (1999). Science's new social contract with society.

Nature. https://doi.org/10.1038/35011576

Giddens, A. (1991). Modernity and Self and : society in the Late Modern Age. In *Self*. https://doi.org/10.1111/1467-9566.ep11343722

Giorgio, T. D., & Brophy, S. P. (2001). Challenge-Based Learning in Biomedical Engineering: A Legacy Cycle for Biotechnology. *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition*.

Graneheim, U. H., Lindgren, B. M., & Lundman, B. (2017). Methodological challenges in qualitative content analysis: A discussion paper. *Nurse Education Today*, *56*, 29–34. https://doi.org/10.1016/j.nedt.2017.06.002

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: Concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today*, *24*(2), 105–112. https://doi.org/10.1016/j.nedt.2003.10.001

Grossen, M. (2008). Methods for studying collaborative creativity: An original and adventurous blend. *Thinking Skills and Creativity*. https://doi.org/10.1016/j.tsc.2008.09.005

Hadzigeorgiou, Y. (2005). Romantic understanding and science education. *Teaching Education*, *16*(1), 23–32. https://doi.org/10.1080/1047621052000341590

Hadzigeorgiou, Y., Fokialis, P., & Kabouropoulou, M. (2012). Thinking about Creativity in Science Education. *Creative Education*, *3*(5), 603–611.

Halpern, D. F., & Hakel, M. D. (2003). Applying the Science of Learning to the University and Beyond: Teaching for Long-Term Retention and Transfer. *Change: The Magazine of Higher Learning*. https://doi.org/10.1080/00091380309604109

Hämäläinen, R., & Vähäsantanen, K. (2011). Theoretical and pedagogical perspectives on orchestrating creativity and collaborative learning. *Educational Research Review*, *6*, 169–184.

Harris, I. (2003). What does “the discovery of grounded theory” have to say to medical education? *Advances in Health Sciences Education*, *8*(1), 49–61. https://doi.org/10.1023/A:1022657406037

Harvey, L., & Green, D. (2006). Assessment & Evaluation in Higher Education Defining Quality, (June 2013), 37–41.

Haylock, D. W. (1987). A framework for assessing mathematical creativity in school chilren. *Educational Studies in Mathematics*. https://doi.org/10.1007/BF00367914

Healey, M. (2005). Linking research and teaching to benefit student learning. *Journal of Geography in Higher Education*. https://doi.org/10.1080/03098260500130387

Hill, D. (n.d.). British Journal of Sociology of Education State Theory and the Neo- Liberal Reconstruction of Schooling and Teacher Education : A structuralist neo-Marxist critique of postmodernist , quasi- theory, (2000), 37–41.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*(3), 235–266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99–107. https://doi.org/10.1080/00461520701263368

Hossieni, A. O. S., & Khalili, S. (2011). Explanation of creativity in postmodern educational ideas. *Procedia - Social and Behavioral Sciences*, *15*, 1307–1313. https://doi.org/10.1016/j.sbspro.2011.03.283

Hu, W., & Adey, P. (2002). A scientific creativity test for secondary school students. *International Journal of Science Education*, *24*(4), 389–403.

Hu, W., Shi, Q., Han, Q., Wang, X., & Adey, P. (2010). Creative Scientific Problem Finding and Its Developmental Trend. *Creativity Research Journal*, *22*(1), 46–52.

Hu, W., Wu, B., Jia, X., Yi, X., Duan, C., Meyer, W., & Kaufman, J. (2013). Increasing Students' Scientific Creativity: The "Learn to Think" Intervention Program. *The Journal of Creative Behavior*, *47*(1), 3–21.

Huang, P. S., Peng, S. L., Chen, H. C., Tseng, L. C., & Hsu, L. C. (2017). The relative influences of domain knowledge and domain-general divergent thinking on scientific creativity and mathematical creativity. *Thinking Skills and Creativity*, *25*, 1–9. https://doi.org/10.1016/j.tsc.2017.06.001

Humphrey, J. D., Coté, G. L., Walton, J. R., Meininger, G. A., & Laine, G. A. (2005). A new paradigm for graduate research and training in the biomedical sciences and engineering. *Advances in Physiology Education*. https://doi.org/10.1152/advan.00053.2004

Hung, W. (2011). Theory to reality: A few issues in implementing problem-based learning. *Educational Technology Research and Development*. https://doi.org/10.1007/s11423-011-9198-1

Hunsaker, S. L. (2005). Outcomes of Creativity Training Programs. *Gifted Child Quarterly*, *49*(4), 292–299. https://doi.org/10.1177/001698620504900403

Illeris, K. (2016). *How we learn: Learning and non-learning in school and beyond: Second edition*. *How We Learn: Learning and Non-Learning in School and Beyond: Second Edition*. https://doi.org/10.4324/9781315537382

Joham, C., & Clarke, M. (2012). Teaching critical management skills: The role of problem-based learning. *Teaching in Higher Education*, *17*(1), 75–88. https://doi.org/10.1080/13562517.2011.590975

Justice, C., Rice, J., Roy, D., Hudspith, B., & Jenkins, H. (2009). Inquiry-based learning in higher education: Administrators' perspectives on integrating inquiry pedagogy into the curriculum. *Higher Education*, *58*(6), 841–855. https://doi.org/10.1007/s10734-009-9228-7

Kaufman, I. J. C., Richards, R., & Hospital, M. (2007). Everyday creativity: process and way of life—four key issues. *Creativity*.

https://doi.org/10.1017/cbo9780511763205.013

Khan, H., Taqui, A. M., Khawaja, M. R., & Fatmi, Z. (2007). Problem-based versus conventional curricula: Influence on knowledge and attitudes of medical students towards health research. *PLoS ONE*, *2*(7). https://doi.org/10.1371/journal.pone.0000632

Khanova, J., Roth, M. T., Rodgers, J. E., & Mclaughlin, J. E. (2015). Student experiences across multiple flipped courses in a single curriculum. *Medical Education*, *49*(10), 1038–1048. https://doi.org/10.1111/medu.12807

Klein-Gardner, S. S., Brophy, S. P., Aston, M. J., & Paschal, C. B. (2010). Biomedical imaging education: Safe, inexpensive hands-on learning. *International Journal of Engineering Education*.

Klein, J. T. (2004). Interdisciplinarity and complexity: An evolving relationship. *E:CO Emergence: Complexity and Organization*. https://doi.org/10.emerg/10.17357.5b032d0fdc094281a75e3ff2f998d161

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of Science and Scientific Inquiry as Contexts for the Learning of Science and Achievement of Scientific Literacy. *International Journal of Education in Mathematics Science and Technology (IJEMST) International Journal of Education in Mathematics Science and Technology International Journal of Education in Mathematics Science and Technology*, *1*(3), 138–147. https://doi.org/10.18404/ijemst.19784

Lee, V. S. (2012). What is inquiry-guided learning? *New Directions for Teaching and Learning*, (129), 5–14. https://doi.org/10.1002/tl.20002

Lélé, S., & Norgaard, R. B. (2005). Practicing Interdisciplinarity. *BioScience*. https://doi.org/10.1641/0006-3568(2005)055[0967:PI]2.0.CO;2

Litmanen, T., Lonka, K., Inkinen, M., Lipponen, L., & Hakkarainen, K. (2012). Capturing teacher students' emotional experiences in context: Does inquiry-based learning make a difference? *Instructional Science*, *40*(6), 1083–1101.

https://doi.org/10.1007/s11251-011-9203-4

Lowell, J., Utah, B., Verleger, M., & Beach, D. (2013). The Flipped Classroom : A Survey of the Research The Flipped Classrom : A Survey of the Research. *Proccedings of the Annual Conference of the American Society for Engineering Education*, 6219.

Ma, H. H. (2006). A synthetic analysis of the effectiveness of single components and packages in creativity training programs. *Creativity Research Journal*, *18*(4), 435–446. https://doi.org/10.1207/s15326934crj1804_3

Martinez-Muneta, M. L., de Avila, M. L., Romero, G., & Felez, J. (2015). Searching for the Most Creative Engineer. *International Journal of Engineering Education*.

Matthew, C. T., & Sternberg, R. J. (2006). Leading Innovation through Collaboration. *Advances in Interdisciplinary Studies of Work Teams*. https://doi.org/10.1016/S1572-0977(06)12002-6

Mesko B. (2017). *The guide to the future of medicine: Technology and the human touch.* 2^{nd} ed. Budapest: Webicina Kft.

Miell, D. & Littleton, K. (2004). *Collaborative creativity, contemporary perspectives*. London: Free Associate Books.

Miller, E. R. (2015). Improve undergraduate science education. *Nature*, *523*(7560), 282–284. https://doi.org/10.1038/523282a

Minstrell, J., & Zee, E. H. Van. (2000). Inquiring into Inquiry Learning and Teaching in Science Edited by. *Advancement Of Science*, 1–516. Retrieved from http://ehrweb.aaas.org/PDF/InquiryFM.pdf

Morin, E. (1999). Los siete saberes necesarios para la educación del futuro. *Revista De Innovación E Investigación Educativa*, 60. https://doi.org/fdg

Morin, E. (2001). Seven Complex Lessons in Education for the Future: Education on the Move, 92. https://doi.org/citeulike-article-id:13337437

Murray-Harvey, R., Curtis, D. D., Cattley, G., & Slee, P. T. (2005). Enhancing teacher education students' generic skills through problem-based learning. *Teaching Education*, *16*(3), 257–273. https://doi.org/10.1080/10476210500205025

Nakamura, J., & Csikszentmihalyi, M. (2014). The concept of flow. In *Flow and the Foundations of Positive Psychology: The Collected Works of Mihaly Csikszentmihalyi*. https://doi.org/10.1007/978-94-017-9088-8_16

Neumann, C. (2007). Fostering Creativity: A model for developing a culture of collective creativity in science. *EMBO Reports*, *8*(3), 202–207.

Nieto Martín, S. (2010). *Principios, métodos y técnicas esenciales para la investigación educativa*. 1st ed. Madrid: Dykinson

O'Flaherty, J., & Phillips, C. (2015). The use of flipped classrooms in higher education: A scoping review. *Internet and Higher Education*. https://doi.org/10.1016/j.iheduc.2015.02.002

Oandasan, I., & Reeves, S. (2005). Key elements for interprofessional education. Part 1: The learner , the educator and the learning context. *Journal of Interprofessional Care*, *1*, 20–38. https://doi.org/10.1080/13561820500083550

Osborne, J., & Dillon, J. (2008). Science education in Europe: Critical reflections. *London: Nuffield Foundation*.

Palincsar, A. (1998). Social constructivist perspectives on teaching and learning. *Annual Reviews in Psychology*, *49*, 345–375.

Papathanasiou, I. V., Kleisiaris, C. F., Fradelos, E. C., Kakou, K., & Kourkouta, L. (2014). Critical thinking: The development of an essential Skill for nursing students. *Acta Informatica Medica*, *22*(4), 283–286. https://doi.org/10.5455/aim.2014.22.283-286

Pérez Urrestarazu, L., Franco Salas, A., & Fernández Cañero, R. (2011). Multidisciplinary education for new landscape engineering concepts using problem-based collaborative learning. A case study in Spain. *International Journal of Engineering Education*.

Piaget, J. (1977). *The development of thought : equilibration of cognitive structures*. Viking Press. Retrieved from http://psycnet.apa.org/record/1979-20791-000

Plucker, J. A., Beghetto, R. A., & Dow, G. T. (2004a). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educational Psychologist*, *39*(2), 83–96. https://doi.org/10.1207/s15326985ep3902_1

Qu, S. Q., & Dumay, J. (2011). The qualitative research interview. *Qualitative Research in Accounting & Management*. https://doi.org/10.1108/11766091111162070

Quitadamo, I. J., & Kurtz, M. J. (2007). Learning to improve: Using writing to increase critical thinking performance in general education biology. *CBE Life Sciences Education*. https://doi.org/10.1187/cbe.06-11-0203

Ranson, S. (1992). Towards the Learning Society. *Educational Management Administration & Leadership*. https://doi.org/10.1177/174114329202000202

Ribeiro Piske, F. H., Stoltz, T., Guérios, E., de Camargo, D., de Freitas, S. P., & Dias, C. L. (2017). Complexity in Promoting a Teaching to Develop Creativity of Gifted Students: Contributions from Morin and Jung. *Creative Education*, *08*(06), 925–934. https://doi.org/10.4236/ce.2017.86067

Richards, L. G. (1998). Stimulating creativity: teaching engineers to be innovators. *28th Annual Frontiers in Education Conference, 1998. FIE'98.* https://doi.org/10.1109/FIE.1998.738551

Rodríguez, G., Zhou, C., & Carrio, M. (2017). Creativity in biomedical education: Senior teaching and research staff's conceptualization and implications for pedagogy development. *International Journal of Engineering Education*, *33*(1), 30–43.

Rodríguez G., Baños J.E., Carrió, M. (2017). Fostering Creativity through Inquiry-Based Learning in Biomedical Education. In: Zhou C, editor. *Creative Problem-Solving Skill Development in Higher Education*. 1st ed. Hershey (PA): IGI Global; p. 116-134.

Roskos-Ewoldsen, B., Black, S. R., & Mccwon STEVEN. (2008). Age-related Changes in Creative Thinking. *The Journal of Creative Behavior*. https://doi.org/10.1002/j.2162-6057.2008.tb01079.x

Runco, M. A. (2014a). *Creativity: Theories and Themes: Research, Development, and Practice*. *Creativity: Theories and Themes: Research, Development, and Practice*. https://doi.org/10.1016/C2012-0-06920-7

Runco, M. A. (2014b). Enhancement and the Fulfillment of Potential. In *Creativity*. https://doi.org/10.1016/B978-0-12-410512-6.00012-6

Savery, J. R. (2006a). Overview of Problem-based Learning : Definitions and Distinctions. *Interdisciplinary Journal of Problem-Based Learning*, *1*(1), 9–20. https://doi.org/10.7771/1541-5015.1002

Sawyer, K. R. (2006). *Explaining Creativity - The Science if Human Innovation*. *Creativity and Consciousness: Philosophical and …*. https://doi.org/10.1016/0140-1750(88)90050-4

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. J. (2011). The process of problem-based learning: What works and why. *Medical Education*, *45*(8), 792–806. https://doi.org/10.1111/j.1365-2923.2011.04035.x

Schmidt, H. G., Vermeulen, L., & Van Der Molen, H. T. (2006). Longterm effects of problem-based learning: A comparison of competencies acquired by graduates of a problem-based and a conventional medical school. *Medical Education*, *40*(6), 562–567. https://doi.org/10.1111/j.1365-2929.2006.02483.x

Schwartzman, J. (1977). Art , Science , n and Change in. *American Anthropological Association*, *5*(3), 239–262.

Scott, G., Leritz, L. E., & Mumford, M. D. (2004a). The Effectiveness of Creativity Training : A Quantitative Review. *Creativity Research Journal*, *16*(4), 361–388.

Sharp, P. A., & Langer, R. (2011). Promoting convergence in biomedical science. *Science*. https://doi.org/10.1126/science.1205008

Simmons, J. & Inabinet B. (2018). Retooling the Discourse of Objectivity: Epistemic Postmodernism as Shared Public Life. *Public Culture*; *30* (2): 221–243. doi: https://doi.org/10.1215/08992363-4310862

Smith, T. E., Rama, P. S., & Helms, J. R. (2018). Teaching critical thinking in a GE class: A flipped model. *Thinking Skills and Creativity*, *28*(November 2017), 73–83. https://doi.org/10.1016/j.tsc.2018.02.010

Smyrnaiou, Z., Georgakopoulou, E., Sotiriou, M., & Sotiriou, S. (2017). The learning science through theatre initiative in the context of responsible research and innovation. In *IMSCI 2017 - 11th International Multi-Conference on Society, Cybernetics and Informatics, Proceedings*.

Spronken-Smith, R., & Walker, R. (2010). Can inquiry-based learning strengthen the links between teaching and disciplinary research? *Studies in Higher Education*, *35*(6), 723–740. https://doi.org/10.1080/03075070903315502

Spronken-Smith, R., Walker, R., Batchelor, J., O'Steen, B., & Angelo, T. (2012). Evaluating student perceptions of learning processes and intended learning outcomes under inquiry approaches. *Assessment & Evaluation in Higher Education*, *37*(1), 57–72. https://doi.org/10.1080/02602938.2010.496531

Sternberg, R. J. (1999). *Handbook of creativity*. *Cambridge University Press*. https://doi.org/http://ebooks.cambridge.org/ebook.jsf?bid=CBO9780511763205

Stilgoe, J., Owen, R., & Macnaghten, P. (2013). Developing a framework for responsible innovation. *Research Policy*. https://doi.org/10.1016/j.respol.2013.05.008

Stockwell, B. R., Stockwell, M. S., Cennamo, M., & Jiang, E. (2015). Blended Learning Improves Science Education. *Cell*, *162*(5), 933–936. https://doi.org/10.1016/j.cell.2015.08.009

Tan, O. (2009). *Problem-Based Learning and Creativity* (Cengage Le). Singapore.

Thomé, A. M. T., Scavarda, L. F., Scavarda, A., & Thomé, F. E. S. de S. (2016). Similarities and contrasts of complexity, uncertainty, risks, and resilience in supply chains and temporary multi-organization projects. *International Journal of Project Management*. https://doi.org/10.1016/j.ijproman.2015.10.012

Thongpravati, O., Maritz, A., & Stoddart, P. (2016). Fostering Entrepreneurship and Innovation through a Biomedical Technology PhD Program in Australia *. *International Journal of Engineering Education*.

Topol, EJ. (2013). *The creative destruction of medicine: How the digital revolution will create better health care*. New York: Basic Books.

Vaessen, B. E., van den Beemt, A., van de Watering, G., van Meeuwen, L. W., Lemmens, L., & den Brok, P. (2017). Students' perception of frequent assessments and its relation to motivation and grades in a statistics course: a pilot study. *Assessment and Evaluation in Higher Education*, *42*(6), 872–886. https://doi.org/10.1080/02602938.2016.1204532

Vygotsky, L. S. (1978). Mind in society. *Mind in Society*, *Mind in So*, 159. https://doi.org/10.1177/1359104511414265

Wain, K. (2000). The learning society: Postmodern politics. *International Journal of Lifelong Education*, *19*(1), 36–53. https://doi.org/10.1080/026013700293449

Wain, K. (2008). The future of education ... and its philosophy. *Studies in Philosophy and Education*, *27*(2), 103–114. https://doi.org/10.1007/s11217-007-9093-8

Waldrop, M. M. (2015). the Science of Unethical To Teach. *Nature*, *523*, 272–274.

Wechsler, S. M., Saiz, C., Rivas, S. F., Vendramini, C. M. M., Almeida, L. S., Mundim, M. C., & Franco, A. (2018). Creative and critical thinking: Independent or overlapping components? *Thinking Skills and Creativity*, *27*(January 2017), 114–122. https://doi.org/10.1016/j.tsc.2017.12.003

Wenger, E. (2003). *Communities of practice: learning, meaning and identity*. *Journal of Mathematics Teacher Education*. https://doi.org/10.1023/A

White, B. Y. (1993). ThinkerTools: Causal Models, Conceptual Change, and Science Education. *Cognition and Instruction*. https://doi.org/10.1207/s1532690xci1001_1

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008). Physics. PhET: Simulations that enhance learning. *Science*. https://doi.org/10.1126/science.1161948

Woods, N. N. (2007). Science is fundamental: The role of biomedical knowledge in clinical reasoning. *Medical Education*. https://doi.org/10.1111/j.1365-2923.2007.02911.x

Yew, E. H. J., Chng, E., & Schmidt, H. G. (2011). Is learning in problem-based learning cumulative? *Advances in Health Sciences Education*, *16*(4), 449–464. https://doi.org/10.1007/s10459-010-9267-y

Zhou, C. (2012a). Fostering creative engineers: A key to face the complexity of engineering practice. *European Journal of Engineering Education*, *37*(4), 343–353. https://doi.org/10.1080/03043797.2012.691872

Zhou, C. (2012b). Integrating creativity training into Problem and Project-Based Learning curriculum in engineering education. *European Journal of Engineering Education*, *37*(5), 488–499. https://doi.org/10.1080/03043797.2012.714357

Zhou, C., & Luo, L. (2012). Group Creativity in Learning Context: Understanding in a Social-Cultural Framework and Methodology. *Creative Education, 3*(4), 392–399.

Zhou, C. (2015). Bridging creativity and group by elements of problem-based learning (PBL). In *Advances in Intelligent Systems and Computing* (Vol. 355, pp. 1–9). https://doi.org/10.1007/978-3-319-17398-6_1

Zhou, C. ., & Shi, J. . (2015). A cross-cultural perspective to creativity in engineering education in problem-based learning (PBL) between Denmark and China. *International Journal of Engineering Education*.

Zhou, C. (2016). Developing creativity as a Scientific Literacy in Software Engineering Education towards Sustainability. In 2016 12th International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery (ICNC-FSKD 2016). *IEEE Press*.

Zhou, C. (2017). *Creative Problem-Solving Skill Development in Higher Education*. 1st ed. Hershey (PA): IGI Global.