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Analysing activities in the Portuguese secondary schools' Science Learning Studios

A thesis submitted in partial fulfilment of the requirements for a PhD degree in Educational Sciences, specialisation in Curriculum Theory and Development

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> Once the validity of this mode of thought has been recognized, the final results appear almost simple; any intelligent undergraduate can understand them. But the years of searching in the dark, for a truth that one feels, but cannot express; the intense desire and the alternations of confidence and misgiving, until one breaks through to clarity and understanding, are only known to him who has himself experienced them. (Einstein, 1933, The Origin of the General Theory of Relativity (Einiges über die Entstehung der allgemeinen Relativitätstheorie), delivered as the first George A. Gibson Lecture at the University of Glasgow, 20 June 1933)

As I have come to understand, we are nothing without the Other and the Tools that mediate this relation. So, first, I would like to thank those known and unknown, human and non-human, that inevitably and generously participated in my research activity. In a more canonical way, I would like to thank:

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Preface

Despite the linear construction of the text that follows, and the systematic image of knowledge construction that it sometimes can communicate, this research work was quite non-linear, with *disappointments* with theory and practice, empirical work without a proper theoretical apparatus, development of instruments and intuition leaps in which direction to follow. As this work spanned many years, in a slow pace when compared with a standard 3-year PhD, and the final text only materialised in the last months of this work, it was difficult to make it visible in a work such as a thesis. The transparency of the research process to show these "aporias" and setbacks in practice was, however, one of my concerns. I tried to find ways to make this process visible and some of the ideas and instruments developed in this work (the Digital Research Notebooks, described in chapter 5) are my take on this research problem.

The first main event that led to this thesis was a road trip to the United States East Coast in 2007, to some of the main Science education interest points on that side of the Atlantic. UIED (Unit of Research Education and Development), FCTUNL (School of Sciences and Technology, New University of Lisbon) financially supported this road trip, mentored in part by my supervisor, Prof. Vitor Teodoro, and organised by myself and my colleagues Clara Boavida and Sandra Martins. The main goal was to contact with several universities and research centres with innovative practices and spaces in Mathematics and Science Education. Some of those interest points were the Concord Consortium (Paul Horwitz), Tufts University's Fulcrum Institute (Judah Schwartz), Harvard University's Mazur Group (Eric Mazur), Graduate School of Education (Chris Dede) and Derek Bok Center for Teaching and Learning (Robin Gottlieb), MIT's TEAL project (John Belcher) and North Carolina State University's SCALE-UP project (Robert Beichner). The later initiative was essential in the development of some of the ideas in this thesis.

The second main event was the beginning of my participation, in late 2007, in Parque Escolar's secondary schools' modernisation programme, as part of the team lead by Prof. Vitor Teodoro to develop a new model of Science learning spaces, that would influence the architecture programme of more than one hundred rebuilt schools across the country. With a strong influence from the SCALE-

UP project at NCSU, this participation set the stage for developing much of the research questions in this work.

The third main event was my enrolment in 2008 in the MPhil/PhD Programme at the Department of Education and Professional Studies at King's College London, UK, where I had the opportunity to develop my research skills, participate in the daily life of a group of researchers in Science Education and explore in depth the literature that very much influenced my thinking and practice in further years. The exploratory work, pilot study and literature review that took place with the financial support of a Rosalind Driver Studentship and the material and human resources of this research hub defined much of the work here presented.

The fourth main event was the grant awarded by the Portuguese Foundation for Science and Technology (FCT), following the 2012 Call for Proposals for Scientific Research and Technological Development Projects, to the project PTDC-MHC-CED-5116/2012, Attitudes, expectations and practices in the Portuguese secondary schools' Science laboratories (Principal Investigator – Prof. Vitor Duarte Teodoro), that supported a significant part of this work. It allowed the research team of which I was a member to acquire literature, software and services, do field work in several schools across the country, meet Robin Millar at the University of York and know better his work on practical activity analysis and on the network of Science Learning Centres, discuss some ideas with Robert Beichner in the first European SCALE-UP conference at Nottingham Trent University in 2014, connect to the Stella project in the 2015 NARST annual conference in Chicago, USA, and participate in several international and national conferences on Science Education (ECER, ESERA, ENEC) to discuss and improve our work.

The final main event was the writing of the final thesis that you are about to read, after struggling for 9 years to find my own voice and to write an original contribution to the field. I hope you enjoy the reading.

João Fernandes

Caparica, October 23, 2017

Abstract

The plan for the modernisation of the Portuguese secondary schools' buildings, started in 2007 by Parque Escolar E.P.E, the sixth of this size since the beginning of the XXth century, established a new school building model with a priority intervention in the spaces for Science and Technology. The new model of schools' Science spaces aims to support a variety of teaching strategies, linking theory and practice, aligning itself with the principles of the reform of secondary education and Science curricula.

Unlike the Anglo-American model of Science learning spaces, formalised in a single laboratory for all classes with daily activities of observation and experimentation, the previous Portuguese model included both *regular* classrooms for lectures and laboratories for practical work, especially for students in secondary education. This separation of spaces corresponded to a separation of teaching strategies, with the first devoted mainly to instruction and problem solving, and the later to practical work, near its origins in the university model of Science teaching in the nineteenth century. This bipartite model contrasts with the new design, in line with the Learning Studios and classrooms/environments for active learning, a hybrid space to support instruction, practical work and multiple learning programmes.

Taking advantage of the opportunity offered by the modernisation plan, this project proposed to investigate the attitudes and expectations of teachers about the new model of Science learning Studio as well as inquire about the current situation of teaching and learning activities in these new spaces.

Keywords: learning spaces, school Science laboratories, activity theory, secondary education, active learning, school building and architecture

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Resumo

O plano de modernização do parque escolar das escolas secundárias portuguesas, iniciado em 2007 pela Parque Escolar E.P.E, o sexto com esta dimensão desde o início do séc. XX, instituiu um novo modelo de edifício escolar com uma área de intervenção prioritária no Núcleo de Ciências e Tecnologia. O novo modelo de espaços escolares para as Ciências tem como objetivo suportar uma diversidade de estratégias de ensino-aprendizagem, interligando teoria e prática, alinhando-se com os princípios das reformas mais recentes do ensino secundário e dos currículos de Ciências em particular.

Ao contrário do modelo anglo-americano de espaços para as Ciências, formalizado num único laboratório para todas as aulas com atividade diária de observação e/ou experimentação, o anterior modelo português incluía salas de aula *normais* para aulas teóricas e laboratórios para trabalho prático, laboratorial e/ou experimental, em especial para alunos do ensino secundário. Esta separação de espaços corresponde essencialmente a uma separação de estratégias de ensino, com os primeiros dedicados maioritariamente a instrução e resolução de exercícios, e os segundos a atividades práticas, próximos da sua origem no modelo universitário do ensino das Ciências do século XIX. Este modelo bipartido contrasta com o novo modelo proposto, na linha dos Estúdios de Aprendizagem e das salas de aula/ambientes de aprendizagem ativa, um espaço híbrido de apoio a instrução, trabalho prático e diversos programas de aprendizagem.

Aproveitando a oportunidade única oferecida pelo plano de modernização, a par da emergência de uma nova área de investigação sobre ambientes de aprendizagem ativa das Ciências, este projeto propôs-se investigar as atitudes e expectativas dos professores do ensino secundário sobre os elementos do novo modelo de espaços para o ensino e aprendizagem das Ciências assim como inquirir sobre a situação atual das atividades de ensino e aprendizagem nestes mesmos espaços.

Palavras-chave: espaços de aprendizagem, laboratórios escolares, estúdios de aprendizagem de ciências, teoria da atividade, ensino secundário, arquitetura e construção escolar

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List of abbreviations and acronyms

BAAS - British Association for the Advancement of Science

CCPFCP – "Conselho Científico-Pedagógico de Formação Contínua" (Scientific-Pedagogical council for continuing training)

CDZ – Convergence-Divergence zones

CGPS – Cooperative Group Problem Solving

CSOPM – "Conselho Superior das Obras Públicas e Minas" (High council for public works and mines)

DGAE – "Direcção-Geral da Administração Educativa" (Directorate General for Educational Administration)

dGEE – "Direcção-Geral para o Equipamento Escolar" (Directorate General for School Equipment)

DGPC – "Direção-Geral do Património Cultural" (Directorate General for the Cultural Patrimony)

DLN – Digital Lab Notebook

DRELVT – "Direcção Regional de Educação de Lisboa e Vale do Tejo" (Regional Directorate of Education for Lisbon and the Tagus valley)

DRN – Digital Research Notebook

ECB – "Externato Cooperativo da Benedita" (Cooperative School of Benedita)

EERA – European Educational Research Association

ES – "Escola Secundária" (Secondary school)

ESB – "Escola Superior de Biotecnologia" (Biotechnology School)

ESERA – European Science Education Research Association

GTSCE – "Grupo de Trabalho sobre Construções Escolares" (Working group for school construction)

FCT – Fundação para a Ciência e Tecnologia" (Foundation for Science and Technology)

FCTUNL – School of Sciences and Technology, New University of Lisbon

IST – "Instituto Superior Técnico"

JAEES – "Junta Administrativa do Empréstimo para o Ensino Secundário" (Administrative Board for the Loan for Secondary Education)

JCETS – "Junta das Construções para o Ensino Técnico e Secundário" (Board of Constructions for Technical and Secondary Education)

LBFQ – "Livro Branco da Física e da Química" (White book of Physics and Chemistry)

ME – "Ministério da Educação" (Ministry of Education)

MIT – Massachusetts Institute of Technology

MOP – "Ministério das Obras Públicas" (Ministry of Public Works)

NARST – National Association for Research in Science Teaching

NCSU – North Carolina State University

OCW – Open Courseware

PE – Parque Escolar E.P.E.

PRS – Personal Response System

QDAS – Qualitative Data Analysis Software

SLS – Science Learning Studio

SCALE-UP – Student-centered active learning environment with upside-down pedagogies

SDT – Self-Determination Theory

TEAL – Technology-Enabled Active Learning

UIED – "Unidade de Investigação Educação e Desenvolvimento" (Unit of Research education and Development, New University of Lisbon)

UK – United Kingdom

US – United States

WWII – World War II

1. Introduction

In this introduction, I will provide some background information on the evolution of secondary education, the Science curriculum, pedagogy and spaces in the Portuguese educational system, to in this light explain the context in which the Parque Escolar's modernisation programme arose and how this research project developed into a set of research questions, goals and a formal thesis.

1.1 A changing secondary education

Historically, Portugal has been very precocious in the legislative and political discourse on the importance of school for the modern world. This rhetoric started with compulsory elementary schooling for all in the XVIII^th^ century put into force by Marquês de Pombal, with Portugal being probably the fourth in the world to adopt this model. This measure was not accompanied by the corresponding investment in resources, with the dedicated budget between 1857 and 1902 being just 0.2 % of the GDP, after the Carnation Revolution in 1974 not reaching the 2 %, and only in 1999 rising to 6 %, above the OECD average (Teodoro[1], 2009).

For a significant part of the XX^th^ century, Portugal was or under the rule of a totalitarian regime ("Estado Novo", 1933-1974), or in periods of high political instability in the transition between regimes, first from a monarchy to a republic (late XIX^th^ century to the 1920s) and later from a totalitarian regime to a democracy (1970s-1980s).

The totalitarian regime known as "Estado Novo" ruled Portugal for almost 40 years, and had a particular educational policy limiting access to secondary education, the cradle of both an elite and middle class with social aspirations (Teodoro[2], 1999). It also had a marked control agenda for school practices, materialised in prohibitions of students and teachers' associations, a traditional curriculum,

[1] To not be confounded with the supervisor of this thesis

[2] id.

single textbooks, centrally nominated school head teachers, among others, with schools both closed to the participation of or in the community.

With the end of WWII, in which Portugal took a neutral stand (at least officially), the country inevitably opened to the international scene. Educational reforms took place promoting secondary education to all with the consequent rise in the number of students at this level, especially women, a tendency that endures until the present day. This democratisation process was reinforced after the replacement of the regime in 1974 and later by the agendas of the European Union and other international bodies increasingly influencing national educational policies, aspiring to competitivity, accountability and performativity (Teodoro, 2009). A consequent rise in investment in education followed in the opening of the XXIth century (6 % of the GDP in 1999). The underlying legislative and political discourse called for (1) segmentation of the secondary paths (general, technical, professional) but improving flexibility in changing between paths; (2) a social inclusion rationale (Jordão et al., 2006); (3) the extension of compulsory schooling to 12 years; (4) the opening of the school to the community; (5) the increased use of ICT; (6) shared governance with the community (Ministério da Educação, 2003; Teodoro, 2009).

1.2 A changing secondary Science curriculum

The inclusion of Science in the Portuguese secondary curriculum dates from the first "Liceus", the early designation for secondary schools given in 1836 by Passos Manuel's reform, with subjects such as "Principios de Chimica, de Physica e de Mechanica applicados ás Artes e Officios" and "Principios dos tres Reinos da Natureza applicados ás Artes e Officios" (translating to Principles of Chemistry, Physics and Mechanics applied to the Arts & Crafts and Principles of the Three Kingdoms of Nature applied to the Arts & Crafts, respectively). These subjects roughly correspond to the contemporary Physics, Chemistry, Biology and Geology, with Geography at the time also including content related to Geology (Ministério do Reino, 1836).

Despite some initial concerns in the legislative discourse about the role of secondary schools in providing a general education, and references to the need for applicability of the acquired knowledge to the everyday life of students and the progress of the arts and Sciences (Ministério do Reino, 1836), a strong emphasis on *Learning Science and technology* (Hodson, 2004) has been an essential feature of most secondary Science curricula through the XXth century (Silva, 2008). The post-Sputnik shift in Science education policies, and the subsequent alphabet soup curriculum projects (McComas, 2014) in the US (PSSC, BSCS, CHEM Study, ESCP, TSM, ESS, SCIS, SAPA, ChemCom, BioCom, EarthComm) or in the

UK (Nuffield) emphasising Science as process and STSE in several countries, arrived late in Portugal. Aspects of the nature of Science or Science in the community have been given a marginal role when compared to scientific knowledge.

The creation of departments related to the Educational Sciences in Universities in the 1970s (Ponte, 1993) and connections to the US Universities in the training of Portuguese researchers (OEI, 2003), among others, led the shift in the discourse to more *contemporary* (despite the temporal "décalage") views of a Science curriculum. By the end of the XXth (1989) and early XXIst (2004) centuries, there was a marked shift in secondary Science curriculum reforms. The curriculum documents for scientific subjects reflect a vision of a more humanistic Science education (Aikenhead, 2006) based on: 1) a constructivist perspective on learning with the student with a central role in the process; 2) laboratory, experimental and practical work, through inquiry, encouraging diverse activities, from paper and pencil to field trips and the use of ICT; 3) approaches to the relationship between Science, Technology, Society and Environment (STSE), exploring real contexts that are meaningful to students and society; 4) the incorporation of aspects of the History of Science, approaching multiple factors affecting the evolution of scientific knowledge. The legislative discourse and the curriculum clearly included a dimension of *Learning About Science and Technology*. (Hodson, 2004)

Table 1.1 – A humanistic perspective in school Science (adapted from Aikenhead, 2006, p. 3)

More emphasis on	**Less emphasis on**
Induction, socialisation, or enculturation into students' local, national, and global communities that are increasingly shaped by Science and technology	Induction, socialisation, or enculturation into a scientific discipline
Citizenship preparation for the everyday world	Pre-professional training for the scientific world
Savvy citizens cognizant of the human, social, and cultural dimensions of scientific practice and its consequences	Canonical abstract ideas (curricular content) most often decontextualized from everyday life but sometimes placed in a trivial everyday context
Attention to several Sciences: established Science, frontier Science, and citizen Science	Emphasis on established Science only
Multi-Science approach reflecting international perspectives (including indigenous Science)	Mono-Science approach founded on universalism (Western Science)
Knowledge about Science and scientists	Knowledge of canonical Science
Moral reasoning integrated with values, human concerns, and scientific reasoning	Solely scientific reasoning using scientific habits of mind
Seeing the world through the eyes of students and significant adults	Seeing the world through the eyes of scientists alone
Learning is interacting with the everyday world and includes intellectual achievement, personal change, forming new self-identities, recognising socio-political power, and perhaps practical or social action	Learning is an intellectual task focused on acquiring scientific knowledge and scientific habits of mind
Playing in the subculture of Science as an outsider	Identifying with the subculture of Science as an insider

Besides the scientific subjects' specific curricula, it is worth mentioning that in the school year 2006/07, following the reform of 2004, the subject "Área de Projecto" (Project Area, AP) was briefly introduced in year 12, and later removed in school year 2011/12. The policy discourse positioned this subject as the ideal space and time for students to develop personal and social responsibility, participation, citizenship and a career orientation, giving emphasis to links between school and the community (Ministério da Educação, 2006). One of the practicalities of the lack of a teaching curriculum in this subject, was on one side, the attribution in some cases of Science teachers to classes that had chosen scientific subjects in year 12, and on the other, that at least part of the projects undertaken would be Science-related, some driven by students' interests, others by teachers' interests or a mix of both.

The recent shift in the policy discourse to a Standards-based curriculum in Nuno Crato's period as Minister of Education (2011-2015) and the recent secondary Science curriculum reform in Physics and Chemistry (MEC, 2014) reminds again the aspirations to competitivity, accountability and performativity (Teodoro, 2009), manifesting a technocratic view on what education, and in the case, Science education, should aspire to. Emphasis on curriculum development changed to emphasis on evaluable outcomes.

1.3 A changing secondary Science pedagogy

Secondary school Science took place, for more than one century, in both theoretical lessons and in practical, laboratory and experimental lessons. Practical work is a distinctive feature of school Science as much as the laboratory and has been defended by multiple generations of Science educators.

Solomon, in her book "Teaching children in the laboratory", argues that (1980):

> Science teaching must take place in a laboratory; about that at least there is no controversy. Science simply belongs there as naturally as cooking belongs in the kitchen (...). (p. 13)

If we skim through this quote, we can maybe be led to say that the "laboratory is a kitchen". Apparently, if we look at what is going on in Portuguese schools' Science labs (Dourado & Leite, 2006; Martins et al., 2002), that does not seem far away from the truth. And the "kitchen" is not a very creative kitchen, as students follow recipe-like worksheets to "cook" already known scientific knowledge. Responsibilities for this failure of practical work in Portugal have been attributed to: 1) the weight and type of the final secondary examinations (Jordão, et al., 2006; Silva, 2008); 2) inadequate spaces and infrastructures with several functional problems due to bad design (Heitor et al., 2008); 3) lack of security, insufficient financial resources and audio-visual, technological and scientific equipment

(Martins et al., 2002); 4) inexistent technicians to the laboratories; 5) large classes; 5) and inadequate teacher training (Oliveira, 1999; Valente, 1999).

I agree with Roth and Barton (2004) when they claim that "for (...) Science educators, efforts to promote greater scientific literacy have been shaped by the image of laboratory Science" (p. 22). In the last decade Portugal has invested large sums of money in incentives for practical work with programmes such as "Ensino Experimental das Ciências" (1999 – 2005, Experimental Science Teaching), "Ensino Experimental das Ciências no 1.º Ciclo" (2006 – 2010, Experimental Science Teaching in Primary Schools) or "Concursos Ciência Viva" (1996 – present, Ciência Viva Grants). However, the effectiveness of practical work has yet to be proved, as it is practised in schools in Portugal.

In this regard, several studies have been conducted to investigate the educational effectiveness of practical work in Science education (e.g., Hofstein & Lunetta, 1982, 2004; Lazarowitz & Tamir, 1994; Lunetta, Hofstein, & Clough, 2007). Enquiry-type laboratories have the potential to develop students' abilities and skills such as: "posing scientifically oriented questions, forming hypotheses, designing and conducting scientific investigations, formulating and revising scientific explanations, and communicating and defending scientific arguments". (Hofstein & Mamlok-Naaman, 2007, p. 106)

However, this ideal type of practical work faces the brute reality of real world school laboratory practice. Practical work that takes place in the school lab reflects some of the myths about Science and scientists, which are, according to Hodson (1998):

1. Observation provides direct and reliable access to secure knowledge;
2. Science starts with observation;
3. Science proceeds via induction;
4. Experiments are decisive;
5. Science comprises discrete, generic purposes;
6. Scientific inquiry is a simple, algorithmic procedure;
7. Science is a value-free activity;
8. The so-called "scientific attitudes" are essential to the effective practice of Science;
9. All scientists pose these attitudes (p. 95).

The self-evident role of laboratory and practical work in Science teaching and learning and its effectiveness in attaining cognitive, affective and skills' goals has been seriously questioned by many authors (e.g., Hofstein & Mamlok-Naaman, 2007). Some studies show that most students perceive the purpose of doing laboratory work as following instructions or getting the right answer (Hofstein & Lunetta, 2004). America's Lab Report identified 7 goals for laboratory work: 1) mastering the subject matter; 2) developing scientific reasoning; 3) understanding the complexity and ambiguity of empirical work; 4) developing practical skills; 5) understanding the nature of Science; 6) cultivating interest in

Science and learning Science; 7) and developing teamwork abilities (National Research Council, 2005). It didn't find, however, strong evidence for the achievement of these goals.

Osborne (1998) also builds a case against the distinctive role of the laboratory in Science education on several grounds: demonstrations are much more efficient ways of illustrating phenomena and its scientific description than having a class engaged in phenomenological observation; the objects of Science are essentially iconic, a product of human representation (p. 159).

As Hofstein & Lunetta (1982) pointed out: few teachers in secondary schools are competent to use the laboratory effectively; too much emphasis on laboratory activities leads to a narrow conception of Science; too many experiments performed in school are trivial; laboratory work in schools is often remote from, and unrelated to, the capabilities and interests of the children.

If we seek a more open and humanistic Science education, for both a pipeline of future scientists and the general population pursuing a secondary education, a shift is needed from practical work and its distinctive *temple*, the laboratory, to diverse research-based pedagogies and other models of schools' Science spaces, one of the main themes of this thesis.

1.4 Changing secondary school Science spaces

A *centralisation* tradition in Portugal has been manifested, among other things, in the secondary schools' building initiatives, mostly state controlled. This was the case in the first "Liceus", in the emblematic projects of "Estado Novo" such as the Plan of 1938, or in later initiatives corresponding to the democratisation of access to this educational level such as the "Projectos-Tipo" (Model Projects), followed by the delegation to the Regional Directorates of Education for the construction of new schools (Alegre, 2009).

A constant in the reforms concerning the Science curriculum in Portugal has been the importance given to practical work and the laboratory. Contrary to the UK model of schools' Science classes as taking place only in the laboratory, Science classes in Portugal, in their first appearance in secondary schools, took place in amphitheatres, Chemistry labs and cabinets, later evolved to regular classrooms and laboratories. This separation of spaces roughly corresponded to a separation of learning programmes, with the first being mostly for teacher-centred instruction seeking the acquisition of scientific knowledge by students, and the second dedicated to practice, with students involved in practical work. This dichotomy arose in part from an early teaching tradition of University of Coimbra, in which Chemistry played a central role, and has been undisputed since then.

In 2007, the Portuguese government created Parque Escolar E.P.E., a public company responsible for the planning, management, development and execution of the secondary schools' modernisation programme. The main changes from earlier centralised plans were some of the underlying assumptions of a new school model, that:

> (…) shifts from a teacher centric model (a delivery mode based on transmission of knowledge and passive learning), to one more based on collaboration and exploration (active learning), supported by investigation practices, information gathering and laboratory experimentation and simulation; production of artefacts and reports and its discussion; development of critical thinking, skills in collecting, organizing and analysing information, work in teams, apply knowledge in problem solving, adapt to new situations and technological innovations, develop self-learning skills and the attitude to pursue extra-curricular activities; the decentralisation of the teaching and learning process in both time and space, in particular beyond the classroom; the incentive to extra-classroom activities, involving information search and discussion; the intensive use of computers, ICT and technological devices; the opening of school to the community, promoting lifelong learning and certification. (Parque Escolar, 2009, pp. 11-12)

This new school building model had as a priority intervention the sector for Science and Technology. The new model of schools' Science spaces included in this sector aimed to support a variety of teaching strategies, linking theory and practice (Parque Escolar, 2009), aligning itself with the principles of the reform of secondary education and Science curricula in particular (Ministry of Education, 2003; Jordão et al., 2006).

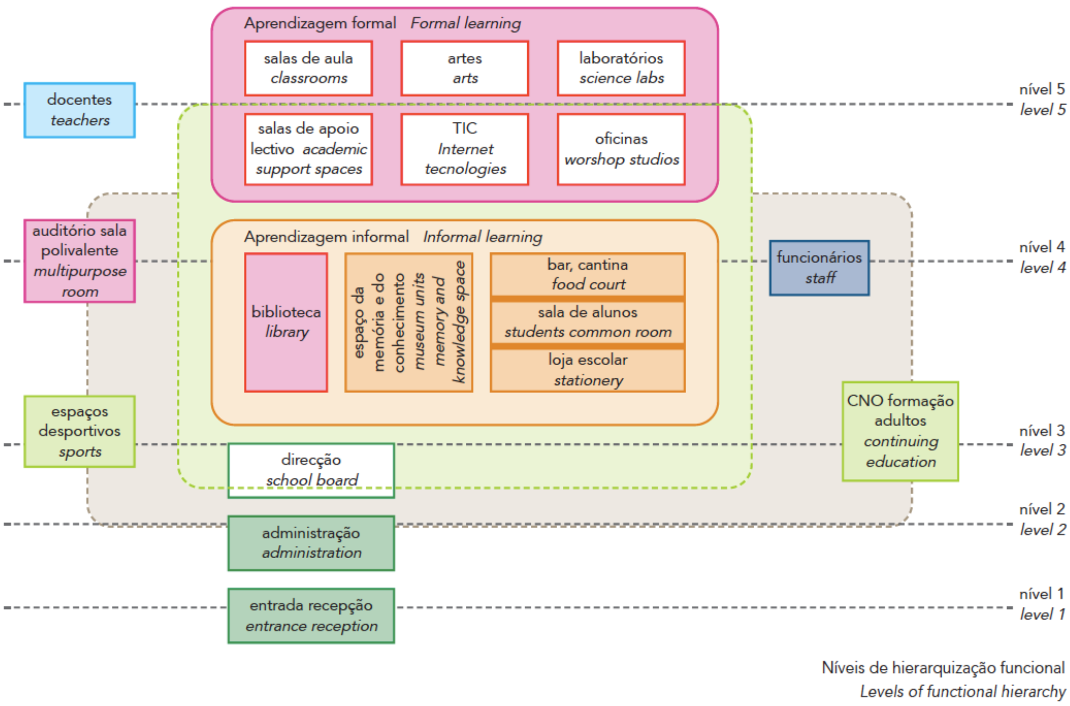

Figure 1.1 – Levels of functional hierarchy of Parque Escolar's conceptual model of modernised schools, including Science labs in level 5 (Parque Escolar, 2009, p. 15)

Two marked differences exist between the earlier dual model and the new model for secondary schools' Science spaces. The first difference concerns the unification of regular classrooms and laboratories into a Science Learning Studio, for all Science lessons, theoretical, practical or with other learning programmes, so that all Science lessons can take place in this space. Flexibility in room arrangements and atypical spaces (with no differences in infra-structure and furniture between Physics, Chemistry, Biology or Geology spaces) were claimed to allow the use of several teaching strategies (lectures, debates, group work, project work, laboratory work, etc.). The second difference relates to the consideration of heterogeneous spaces such as a shared preparation room between every pair of adjacent labs, with transparency and shared equipment, a Science teachers' office close to the laboratories, an external area for outdoor activities, a multi-purpose area for exhibitions and students' informal work and support for digital and online activities (Fernandes et al., 2009).

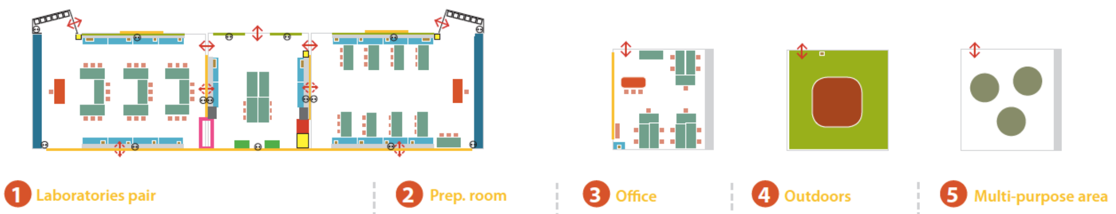

Figure 1.2 – Structuring units of the new model of Science learning spaces (Fernandes et al, 2009)

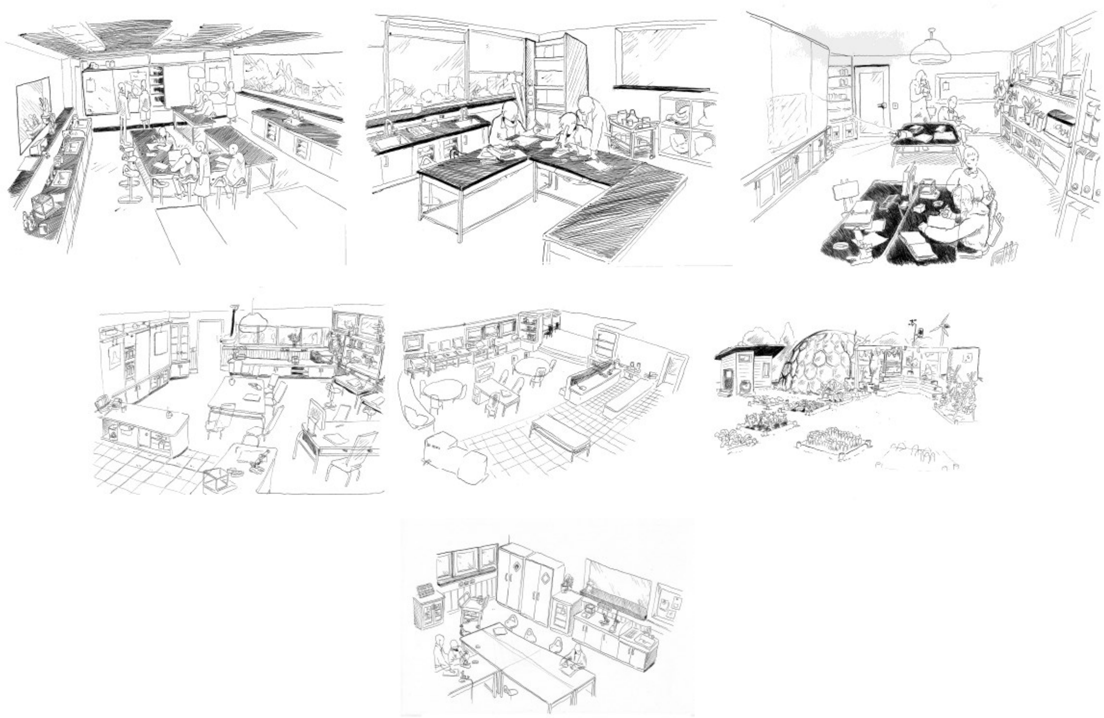

Figure 1.3 – Illustrations of the several structuring units in practice (illustrations by André Pereira, 2014)

1.5 Research questions

The initial draft of the research questions of this thesis, stated in 2008 was the following:

1. How can the practice of Science, research in Science education, and research in the design of learning spaces inform the design of powerful Science learning environments?
2. What is the impact of the present renewing of schools' Science education spaces in Portugal in the practice of school Science?
3. What is the impact of the website containing a set of materials and services that support the renewing of school's Science education spaces in the practice of school Science?

The uneasiness of the evaluative stance of some of these questions for a research work, positionality issues concerning my participation in the rebuilding programme and the progressive immersion in the national and international Science Education literature led me to question the clarity of the initial research questions, and I made a shift. In 2010, I turned to the concept of an open learning environment, materialised in the subject Project Area in year 12, taught by Science teachers to students that chose scientific subjects, and on what practices were being enabled by the new spaces. This broad question guided my ethnographic stance in two schools, as will be described in chapter 6, but I tried to keep the connection to theory and practical lessons, besides the project lessons.

After a period of *disappointment* with school Science in general, following the case studies with ethnographic approaches, I revisited the concept of Physics Studio. This led me to rewrite a research proposal from scratch and later adapt it to the requirements of a 2010 FCT Call for Proposals for Scientific Research and Technological Development Projects, with the mentoring of Prof. Vitor Teodoro. The proposal was not funded on the first application, but in 2012, despite minor changes, was granted a 40 000 € funding, that supported a significant part of the work that led to this thesis. The final research questions, to which this work will try to provide answers, are:

RQ 1. What attitudes and expectations do teachers have towards the new model of Science Learning Studio?

RQ 1.1. What elements of the Studios are more and less valued? Why?

RQ 1.2. How do teachers compare the new model with the previous laboratories/regular classrooms for Science classes?

RQ 2. What teaching and learning activities are taking place in the new Science Learning Studios?

RQ 2.1. To what extent, if any, do the elements of these spaces facilitate or inhibit these activities?

RQ 2.2. How do these activities contrast with previous data from the Portuguese White Book of Physics and Chemistry?

RQ 2.3. What are teachers perceived needs regarding the organisation, management and use of the new Science Learning Studios in these activities?

RQ 3. What are the differences between the idealised and the applied Science Learning Studio model in the intervened schools?

1.6 Goals

The goals of this research are to:

1. Develop personally and professionally as a researcher in Science Education;
2. Extend and refine the concept of Studio to secondary Science Education;
3. Inform the improvement of the model of Science Learning Studio;
4. Develop an activity analysis methodology to analyse activities in the Science Learning Studios;
5. Develop practical and useful solutions for teachers' and student's everyday lives in using the Science Learning Studio for the teaching and learning of Science;
6. Create an empirical snapshot for future research and professional development connected with the field.

1.7 Structure of the thesis

The structure of this thesis is the following:

In chapter 1, I provided an overview of the literature on the major changes in the last 100 years at the policy level concerning secondary education, secondary Science curriculum and pedagogy and contrasted it with the lack of fundamental changes in the schools' Science spaces models in this period. I then provided some background on the model of Science Learning Studio proposed for Parque Escolar's secondary schools rebuilding programme beginning in 2007, finishing with the research questions and goals of this thesis.

In chapter 2, I will provide a review of the literature on the ontogeny of spaces for Science and later for Science Education, beginning with alchemical laboratories, followed by university chemical laboratories, amphitheatres, cabinets and workshops, following the transfer of these templates to school Science, while giving emphasis to the Portuguese case. I will then explore the essential features of the Science spaces models put forward by the major schools' construction plans across the XXth century in Portugal, developing a timeline of these models.

In chapter 3, I will engage some of the literature on Learning Studios connected to early years' education, following the Reggio Emilia educational philosophy and its Atelier, the apprenticeship heritage of the Architecture and Design Studios in higher education, and end up reviewing the literature on Physics Studios at the undergraduate level, with a more detailed exploration of the SCALE-UP project in North Carolina State University and TEAL at MIT. I will conclude with a summary of how these multiple perspectives can work together to provide meaning to the concept of Science Learning Studio for secondary Science education.

In chapter 4, after a critique of the concept of active learning environments and of the limitations of the field, I will try to persuade you of the value of Activity Theory to approach the research questions, and then sketch a framework to analyse activities in the Science Learning Studios.

In chapter 5, I will provide the rationale for the methodological design taken in this work, supported by the literature, and then describe the development of a meta-tool to support the entire research project, the Digital Research Notebook.

In chapter 6, I will present the first set of empirical work, based on 5 case studies that 1) evidenced some of the aspects of the Studio concept in Science Education; 2) supported the development of a meta-tool for analysis–of–practice, the concept of Pedagogical Graphic Novel and an Activity Analysis Methodology; 3) enabled the understanding of teacher's attitudes towards several elements of the SLS and implementation issues of the model; and 4) supported the analysis of organisation and management aspects of the SLS.

In chapter 7, I will present the design, deployment and data analysis of a digital survey to teachers teaching in the SLS in the rebuilt schools, putting forward some possible answers to a significant part of the research questions.

In chapter 8, I conclude this thesis systematising its contribution to knowledge, the limitations of the study and its possible implications at multiple scales, describing some of the development work associated with this research, centred on the development of a model of organisation, management and support for the SLS, a professional development course and the website "Laboratórios Escolares".

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2. From alchemical laboratories to school Science spaces – A review

In the following chapter, I will sketch an ontogeny of the Portuguese schools' Science spaces, departing from the alchemical laboratories, following the emergence of university chemical laboratories for teaching and the parallel evolution of cabinets and workshops, to then trace the *laboratorisation* of school Science, focusing on the Portuguese case. After that, I will conclude with some detail on the main options taken by architects and technical teams concerning schools' Science spaces in the major building programmes across the XXth century, problematize the historical inertia of the separation of spaces for theory and practice in school Science and present the Science Learning Studio as a possible solution for that same historical inertia.

2.1 Alchemical laboratories

The word laboratory, from the latin *laborare* (to work) and *–orium* (a place to perform that work) can also be seen as a conjunction of the words *labor* (work) and *orare* (to pray), at least if we look at its alchemical versions, from Geber in the VIIIth century to those of Newton or Boyle in the XVIIth century. Alchemy, where laboratories and its furnaces had great importance, attempted to accelerate in the laboratory the perfection to which Nature tends to. Robert Boyle, an alchemist, suggested that experiments should be done on Sundays, in a kind of divine worship. The moral implications of the transmutation of plumb to gold implied that this knowledge should only be available to those that were worthy of it and that practical work should follow prayer, mixing spirituality and experiment (Crosland, 2005). In the work "Amphitheatrum Sapientiae Aeternae'" by Heinrich Khunrath (1605), the alchemist is represented in prayer in an oratory, next to the experimentation area.

Figure 2.1 – “Amphitheatrum Sapientiae Aeternae” by Heinrich Khunrath (Public domain)

Laboratories were places dedicated to the practical rather than the theoretical investigation of Nature, with emphasis on manual work and apparatus, a contrast with the early Universities and its Humanities curricula based on learning from books and magisterial lessons by professors. The low status of manual work in universities in the XVIth and XVIIth centuries, together with its results, are evident in Thomas Hobbes view of the lesser status of practical men, such as apothecaries, gardeners or rude mechanics (Crosland, 2005).

In alchemical laboratories, we could find furnaces, fuel, water supply, a sink, flasks, retorts, labelled reactants. Natural light, ventilation, isolation and cleanliness were also essential, with stone floors or plain earth to avoid fires, and a table as workbench and shelves for storage.

A laboratory does not accommodate at least three features of natural objects:

> (…) first, it does not need to put up with an object as it is, it can substitute transformed and partial versions. Second, it does not need to accommodate the natural object where it is, anchored in a natural environment; laboratory Sciences bring objects “home” and manipulate them on their own terms, in the laboratory. Third, a laboratory Science need not accommodate an event when it happens; it can dispense with natural cycles of occurrence and make events happen frequently enough for continuous study. Of course, the history of Science is also a history of lost opportunities and varying successes in accomplishing these transitions. But it should be clear that not having to confront objects within their natural orders is epistemically advantageous for the pursuit of Science; laboratory practice entails the detachment of objects from their natural environment and their installation in a new phenomenal field defined by social agents. (Knorr-Cetina, 1999, p. 27)

These features of the laboratory came to be useful in the utilitarian aspects of alchemical knowledge, supporting the transition to chemistry in the XVIIth century.

2.2 From Chemistry research laboratories to teaching laboratories in universities

The Royal Academy of Sciences in Paris opened its first chemical laboratory in 1668, with several furnaces, cabinets with apparatus and tables, used mostly in the chemical analysis of plants by distillation. At the same time, Luis XIV outlawed laboratories not in the hands of a professor of Chemistry, doctor or apothecary.

The fall of Alchemy in the XVIIIth century and the rise of Chemistry saw, for example, Macquer, in his Dictionary of Chemistry (1771, 1778) giving some guidelines for the construction of Chemistry laboratories:

> (...) although quite a few chemistry laboratories had been constructed in cellars, this was not advisable because of the dampness. Such a situation had a detrimental effect on many chemicals, labels on jars, and on apparatus generally, especially on any metallic parts. Turning to the subject of ventilation, he proposed two large openings at opposite ends of the room to provide a flow of air to carry away noxious vapours. There should be a fireplace, as large as possible, covered with a hood at a sufficient height for the operator to pass underneath. Details of several furnaces were given. The walls of the laboratory should be well supplied with shelves for chemicals and apparatus. There should be a source of water (a fountain is mentioned) and, if possible, a sink. A large table should be placed in the centre of the room as a workbench. As the furnaces would require a constant coal supply, and coal dust made everything dirty, there should be a coal bunker outside the laboratory. (Crosland, 2005, p. 244)

Lavoisier, nominated in 1775 as commissioner of the French State Gunpowder and Saltpetre Administration, built an important laboratory in the Royal Arsenal that was rich in apparatus (a later inventory listed 13 000 pieces of chemical apparatus and 250 of physical apparatus), in associates and assistants and in meticulous balance sheets to support carefully crafted experiments and observations.

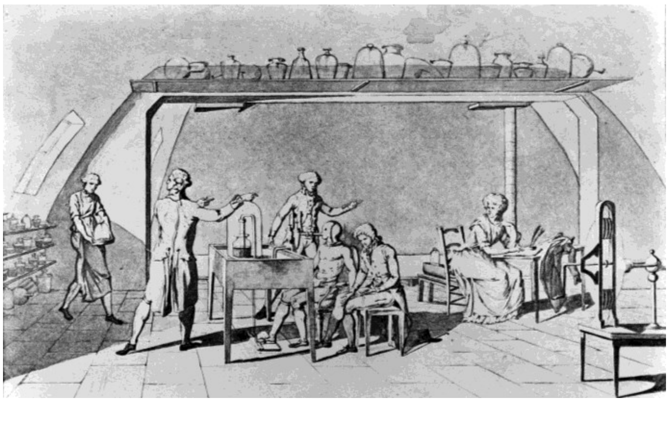

Figure 2.2 - Madame Lavoisier's drawing of an experiment on respiration at work (ca. 1790) (Beretta, 2012)

In the XIX[th] century, laboratories became key in the economy, providing products and processes to the ever-growing manufacturing industry, as Chemistry had its roots not just in alchemy but also metallurgy, pharmacy, the manufacture of pigments and explosives, agriculture and medicine.

Universities started to include Chemistry laboratories in their specialised spaces, such as University of Altdorf, close to Nuremberg.

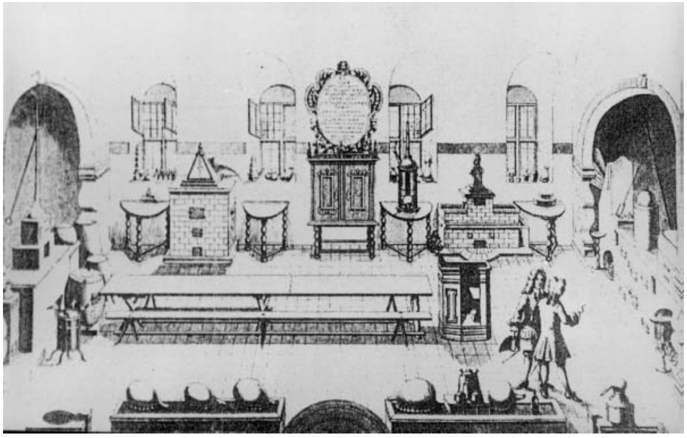

Figure 2.3 - Chemistry laboratory of the University of Altdorf, 1682 (Crosland, 2005, p. 242)

With Chemistry becoming the largest of all Sciences in both manpower and facilities, if a University wanted to teach Chemistry, it had to provide laboratories, spaces exclusive to this subject, something that the other Sciences later followed (Crosland, 2005).

As a University subject in the XIX[th] century, Chemistry was studied as an adjunct to Medicine. In the beginning, students did not participate entirely in chemical experiments, and demonstrations by professors were common. In Germany, with the institution of the PhD, original experimental work was performed by graduate students (Anderson, 2009).

The case for laboratory teaching was made at the University level:

> The École Polytechnique in Paris in the 1790s had demonstrated the value of teaching chemistry, not only by lectures, but also by encouraging students to perform practical work in laboratories. The greatest influence on teaching practical Science through laboratory instruction was, however, that of Justus Liebig at the University of Giessen, who, in the 1820s and 1830s, established an international reputation for teaching chemistry through laboratory practice. This provided an important influence on the general teaching of Science at university level. (Crosland, 2005, p. 252)

Figure 2.4 – Justus von Liebig in his Laboratory at the Chemical Institute of the University of Giessen, c. 1840 (Public domain)

Herman Boerhaave's Leiden University Chemistry teaching laboratory was a European reference in the XVIIIth century. In 1724, with his appointment as professor of Chemistry, Boerhaave demanded the expansion of an adapted laboratory on the periphery of the Leiden Botanic Garden, to accommodate a growing number of students. Four former Scottish Boerhaave's students were chosen to teach medicine in 1726 in the University of Edinburgh, with two of them teaching Chemistry according to Boerhaave's principles. Again, they developed a laboratory next to a Botanic Garden, as much of what was taught and demonstrated involved the use of plants to produce pharmaceuticals, which were also sold to local apothecaries (Anderson, 2009).

The demonstration bench, in a way similar to anatomical theatres were students gathered around the professor dissecting a body, was one of the elements of chemical teaching rooms, as the Royal Institution's New Discoveries in Pneumatics caricature by James Gillray shows.

Figure 2.5 - New Discoveries in Pneumaticks! or - an Experimental Lecture on the Powers of Air in 1802 (Royal Institution, 2016)

A store room can be seen on the back, with glassware and other equipment. The University College London' new building in 1828 included, for example, a large semi-circular teaching theatre, attached to a laboratory for use by the professor (Anderson, 2009).

Around 1900, shortly after the Natural Science Lab had become an established feature of European universities, many photographs were taken to document the lab's inner workings, creating different iconographies of the modern laboratory (Klonk, 2016, p. 50).

Figure 2.6 - Prof. Dastre, Director of the Laboratory of Physiology, in the Sorbonne, from: Benedict 1907, 1: 294 (Klonk, 2016, p. 51)

Dastre, the director of the laboratory of Physiology of the Sorbonne, is photographed sitting at a desk with open books, a microscope and test tubes arranged like props, as symbols of the laboratory's experimental projects (Klonk, 2016, p. 52).

These iconographic laboratory portraits from the late XIXth and early XXth century, such as that of Tesla in his laboratory, cannot be read literally, as the *genius* in the laboratory recalling the alchemist-philosopher. The shift to a focus on experiments in progress and everyday life in scientific practice only happened later, such as the work of Swiss photographer Andri Pol, who accompanied scientists at the CERN in Switzerland. Instead of superheroes in white coats, Pol shows the nuclear scientists at CERN as normal people in Bermuda shorts, standing at the coffee dispenser (Klonk, 2016, p. 63).

Figure 2.7 - Menschen am CERN, 2014, by Andri Pol (Klonk, 2016, p. 64)

As a side note on recent trends in professional and research laboratories' design and architecture, five ideas are elicited in Klonk (2016): 1) increase in flexibility and adaptability of servicing and furniture to the changing needs of research projects; 2) transparency facilitating communication of Science-in-action, nonetheless remaining elusive; 3) open spatial systems; 4) signature architecture creating iconic laboratory envelopes as symbols of prestige and quality and; 5) increase in the areas functioning as informal spaces to facilitate communication, exchange and serendipitous encounters.

Figure 2.8 – Lab, by Menno Aden, a digital composition of laboratories in the building by David Chipperfield in the Novartis Campus in Base, Switzerland (Klonk, 2016, p. 83)

Terms such as "interaction", "communication", "collaboration", "creativity", "connection" or "retreat" became common in the writings of architects and commissioning clients alike, considering spaces of theory, spaces of experiment, informal spaces and the intersections in-between (Klonk, 2016, p. 14).

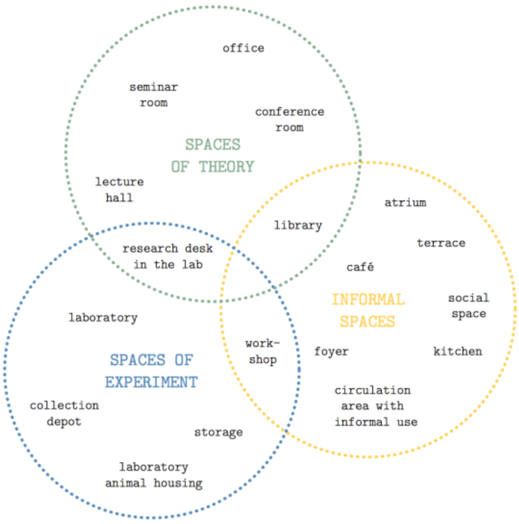

Figure 2.9 - Categories of space according to function (Konk, 2016, p. 124)

2.2.1 The Portuguese Chemistry teaching laboratories

Portugal had two important historical Chemistry laboratories connected to universities. The first, the "Laboratorio Chimico" of the University of Coimbra, followed the reform by Marquês de Pombal in the late XVIIIth century and was based on the model of the Vienna medical school, influenced by the Leiden school of Boerhaave. The chemical laboratory was part of a larger complex for University level Science teaching, including an anatomical theatre, pharmaceutical dispensary, botanical garden, astronomical observatory, cabinets of Physics and Natural History, and museum of Natural Sciences (Casaleiro, 2009). This laboratory model was the first University laboratory in Portugal.

Figure 2.10 – Amphitheatre of the University of Coimbra (left) and first laboratory of the "Laboratorio Chimico" of University of Coimbra (right, Casaleiro, 2009, p. 239)

The second important Chemistry laboratory connected to universities is "Laboratorio Chimico da Escola Polytechnica de Lisboa" (EPL, created in 1837 following the École Polytechnique of Paris), one of the best prepared for teaching and research in the words of August von Hoffmann, creator of the Berlin and Bone University laboratories (Santa-Bárbara & Leitão, 2006). At the time, there were two types of laboratories: research and teaching. This, of the second type, began in what was previously the kitchen of "Colégio dos Nobres", later rebuilt after the fire of 1843 in a project of 1852 by João Pedro Monteiro, and would comprise a total area of 860 square meters, including one amphitheatre that could receive 200 students.

Figure 2.11 – Amphitheatre of the "Laboratorio Chimico of Escola Polytechnica de Lisboa" (Santa-Bárbara & Leitão, 2006, p. 103)

The laboratory space was divided into two parts: one large laboratory (20 m × 12 m × 10 m) for work with 50 students surrounded by a mezzanine providing space for 100 students, with a preparation room; one laboratory, office space and two rooms for storage. From 1855 onwards, rhetorically speaking, practical work was mandatory and so were practical exams, with students in the practical Chemistry course following a set of preparations and analysis contained in a textbook that should be delivered during the admission process (Santa-Bárbara & Leitão, 2006). However, as in Portugal legislation seems to be well advanced of reality, in 1877 experimental teaching was still not being put into practice due to limitations in teaching staff. Rodrigues, one important advocate for the introduction of practical work in teaching at the time, claimed:

> (…) starting in the school year 1890-1891, and that the practical course was covered in two distinct classes, three times a week, two hours per lesson. Student's attendance in chemistry subjects would then start to be accounted, with the same weight, between the sum of the classification obtained in the practical and theoretical courses. The practical course proposed by Rodrigues would consist, at a minimum, of 20 lessons, in which students would be required to execute, at least, 15 out of the 30 works that were annually published in the laboratory in specific tables. The shifts should not exceed the 20 students, distributed in groups of five, required to work "standing, with a special shirt and bareheaded", with classes being held in the gallery. The lower floor

would be devoted exclusively to students who might know more or, in extraordinary cases of high frequency, the shifts that did not exceed eight students. Each student should have a book where he should record a description of the work and the relationship of laboratory equipment used, which would be delivered to the teacher, so the lesson ended, and returned to it the next lesson. It would also be in this book that the teacher would record the score for the frequency of the practical course. (Santa-Bárbara & Leitão, 2006, p. 50)

Figure 2.12 – "Laboratorio Chimico da Escola Polytechnica de Lisboa" (Elvas et al., 2011, p. 188)

2.3 Cabinets and workshops

The Cavendish laboratory in Cambridge, one of its important representatives in the XIXth century, contrasted with earlier spaces for Physics experimentations, either outdoors or in regular rooms with specific apparatus and conditions. Newton's experiments with prisms were made in his room in Trinity College, Cambridge, and only required shutters to be closed, with a small hole in it. The study of trajectories of cannonballs, the barometer experiment suggested by Pascal, the study of lightning conductors by Franklin, all were performed outdoors for the obvious reasons. The study of heat by Rumford took place in a foundry and many experiments that took place indoors only required special apparatus and not a more specific space as Chemistry did (Crosland, 2005).

The Chemistry and Physics cabinet, a term used to refer sometimes to a portable laboratory from the XVIIIth century onwards, was a collection of equipment such as reagents, glassware and blowpipes (Crosland, 2005). The "cabinet de physique" was originally a room with shelves to store apparatus and a table to perform experiments, as the XVIIIth century abbé Nollet's cabinet is a representative.

Figure 2.13 – Nollet in his “cabinet de physique” (Gauvin, 2009)

These cabinets can be said to belong to a tradition dating from earlier cabinets of curiosities, the “Wunderkammer” (Crosland, 2005). Cabinets of curiosities emerged in the XVIth century as rooms exhibiting collections of objects originating from both nature or society, usually owned by wealthy and powerful people or early scientists and can be said to be the precursors of museums. One example is Ole Worms’ XVIIth century cabinet.

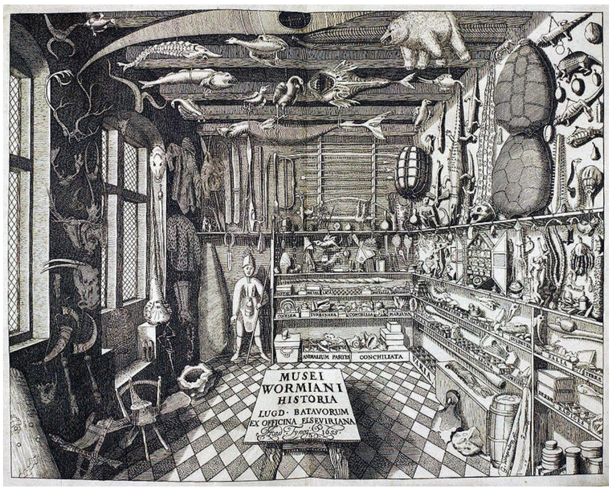

Figure 2.14 - The frontispiece from the Museum Wormianum depicting Ole Worm's cabinet of curiosities (Public domain)

Cabinets cannot be seen in isolation from the spaces where instruments were made, usually known as workshops, where trial experiments also took place. Robert Hooke used these workshops before making public presentations to the members of the Royal Society.

Public demonstrations of Physics experiments were common, in spaces built according to this function, such as lecture theatres, known in Italy as “Teatros fisicos”. Earlier cabinets, workshops and theatres as spaces for Physics experimentation preceded the concept of the laboratory in Physics, which emerged later in the XIX[th] century with the development of current electricity (Crosland, 2005).

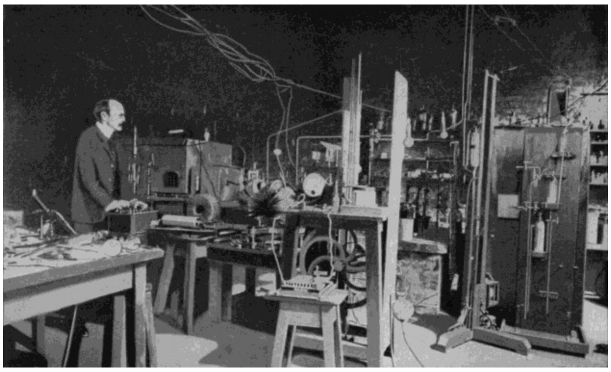

Figure 2.15 - J. J. Thomson in the Cavendish Physical Laboratory (Public domain)

2.4 School Science' spaces

The establishment of laboratory Science as a standard in universities was followed by the *laboratorisation* of school Science, a subject that was starting to gain space in the already packed school curriculum.

The institutionalisation of Science began with the first scientific associations emerging in the late 1660s, the "Académie des Sciences" in Paris and the Royal Society in London, supported by its utilitarian applications and its links to industry, military and power, that influenced the Industrial Revolution, new war technologies and new divisions of labour, changing society at large. However, the separation between abstract Science and applied Science was the first step in a separation process that led to the professionalisation of scientists, a term coined in the XIX[th] century, in the creation of the British Association for the Advancement of Science (BAAS) in 1831. This separation, recalling the separation between the Greeks' pure Sciences and practical technology, and ironically, the separation between the Humanities (dominant in curricula in schools and universities) and Science, was possibly an effort to secure a social niche in XIX[th] century society. The first meetings of the BAAS were organised by themes such as Physics, Chemistry, Geology, Zoology, Botany and others, inspired by the organisation of the new University of Berlin, created in 1810, later applied to the school curriculum (Aikenhead, 2006). August Comte's classification of Sciences reinforced these categories, with Mathematics, Astronomy, Physics, Chemistry, Biology (and Sociology).

Following the institutionalisation of school Science, governments had to provide specific spaces for the recently created subjects. In the remaining chapter, I will explore the essential features of the

Science spaces models put forward by the major schools' construction plans across the XX^{th} century in Portugal, departing from the creation of the first "Liceus". In some of the construction plans, the narrative is incomplete, requiring further historical research to create a more detailed picture of the evolution of schools' Science spaces in the country.

2.5 The Portuguese school construction plans – An evolution of school Science spaces from the early XX^{th} century

The Portuguese system was initially influenced by the French centralised model after the First Republic and Napoleon (Ó, 2009). In 1836, the reform of Passos Manuel created the "Liceus" ("Lycées" in French), giving a stronger focus on the secondary level of public education in Portugal. The goals set for secondary school in the sequence of this reform were more utilitarian, with a shift to an increasing scientific-practical curriculum, focused on the needs of the job market and the "progress of the material civilisation of the country" (Ó, 2009, p. 23). The introduction of the Sciences in the curriculum dates from this time, with its focus on a practical instruction, at least on the legislative discourse. The scientific subjects were at the time "Principles of Physics, Chemistry, Mechanics applied to the Arts and Crafts" and "Principles of Natural History of the three Kingdoms of Nature applied to the Arts and Crafts", followed by other 8 subjects linked to Language, Literature, Moral, Mathematics, Geography, History, Political Economy, Public Administration and Commerce (Ministério do Reino, 1836).

However, the proposed curriculum just lasted until 1844, and its implementation was not made due to economic restraints and lack of social demand. By 1893-94, the total student population in the "Liceus" was 3800, with many opting for private schools. Only in the reform of 1894-1895 by Jaime Moniz was Science to be included again in the curriculum, with a general course of 5 years having as a goal to provide a broader knowledge useful for the active life, and a complementary course, of two years, following the general course, preparing students for University. This reform was influenced by the German system, with the study plans quite like the Prussian organisation of 1892 (Direcção Geral de Instrução Pública, n.d.).

The time attributed to the Sciences was, in the first three years, of two hours per week, later increased to four hours per week and, in the seventh year, to five. From this time also originates the single textbook and the 60 minutes' lessons (except the Illustration subject, with two dedicated hours) and the greater weight given to the exams in this school level. In the legislative document are also guidelines for teaching, with emphasis given to the *presence of objects* for observation by the students, and an *art of lecturing* that gave the word to students in an orderly manner, to assess if the lecture was understood. This was a key reform in the Portuguese secondary schooling system, on which future ones only improved upon, in the words of do Ó (2009, p. 42) and started the ascension of the public "Liceus" over the private offers until the present day.

2.5.1 The first "Liceus" – The case of "Liceu" Passos Manuel

The *laboratorisation* of school Science in Portugal was initially tied to the University of Coimbra, through the template of the "Laboratorio Chimico" as a national reference that brought international prestige, and the tensions between classical studies and more modern studies following the French and German influence. The participation of the vice-rector of the University of Coimbra in the Passos Manuel legislation creating the first "Liceus", and the replacement of the "Real Colégio das Artes" (Royal College of Arts) by the Coimbra "Liceu", keeping its relation to the University (Moniz, 2007), can explain the specification of spaces for Science teaching in Passos Manuel's 1836 legislation.

To support inductive methodologies, these spaces should include a Library, a Chemistry lab and a Cabinet that should have three divisions associated with the "Applications of Physics and Mechanics, Zoology and Mineralogy", an "Experimental garden destined to the applications of Botany" supporting Science teaching and learning in schools. (Ministério do Reino, 1836).

The first "Liceus", architecturally speaking, result from the reforms of 1894-95 by Jaime Moniz and 1905 by Eduardo José Coelho, bringing to life the vision of Passos Manuel dated back from 1836.

The consolidation of the "Liceu real" (Royal "Liceu"), between 1895 and 1930 (Nóvoa, 2005) begins with the construction of "Liceu" Passos Manuel (1882-1911) in Lisbon, the first "Liceu" to apply the requirements for the construction of this kind of schools. Besides "Liceu" Passos Manuel, three other "liceus" are also inaugurated in Lisbon, "Liceu" Camões (1907-09), "Liceu" Pedro Nunes (1909-11), and "Liceu" Maria Amália Vaz de Carvalho (1915-34), and "Liceu" Alexandre Herculano (1914-27) and "Liceu" Rodrigues de Freitas (1918-33), in Oporto. The three projects in Lisbon had the signature of architect Miguel Ventura Terra and the two in Oporto have the signature of architect José Marques da Silva, promoted by "Ministério do Reino" and, after the Republican revolution in 1910, by the "Ministério da Instrução Pública" (Alegre, 2009, p. 8).

These first projects reflect the importance given in the late XIXth century to pedagogical and hygienist views such as the class and semi-boarding regimes, study rooms, reading rooms, dining rooms, active and experimental learning with dedicated spaces (laboratories, museums, cabinets) and equipment (Physics, Chemistry, Geography and Drawing), ventilation and lighting, and spaces dedicated to physical education, such as gymnasiums and outdoor areas, with gardens and kitchen gardens (Parque Escolar, 2010). Before this, the "Liceus" would usually occupy state buildings, adapted to the new uses.

"Liceu" Passos Manuel, formerly known as "Liceu Central de Lisboa", develops from the work of a commission led by António Augusto Aguiar responsible for the choice of place, project and budget, presented in 1882 by architect José Luís Monteiro and revised in 1907 by architect Rosendo Carvalheira.

Typology of spaces

The classical composition of the building has a clear French influence, reflecting the studies by Durand with the programmatic spaces adopted by the French "Lycées" of the second half of the XIXth century: amphitheatre, library, gymnasium and laboratories. The courtyard is the central element, with galleries surrounding it, covered with large windows or open, facilitating the ventilation and lighting of the building interiors, a common concern of hygiene at the time (Alegre, 2009, p. 207).

Figure 2.16 – The construction of "Liceu" Passos Manuel, 1911 (Public domain)

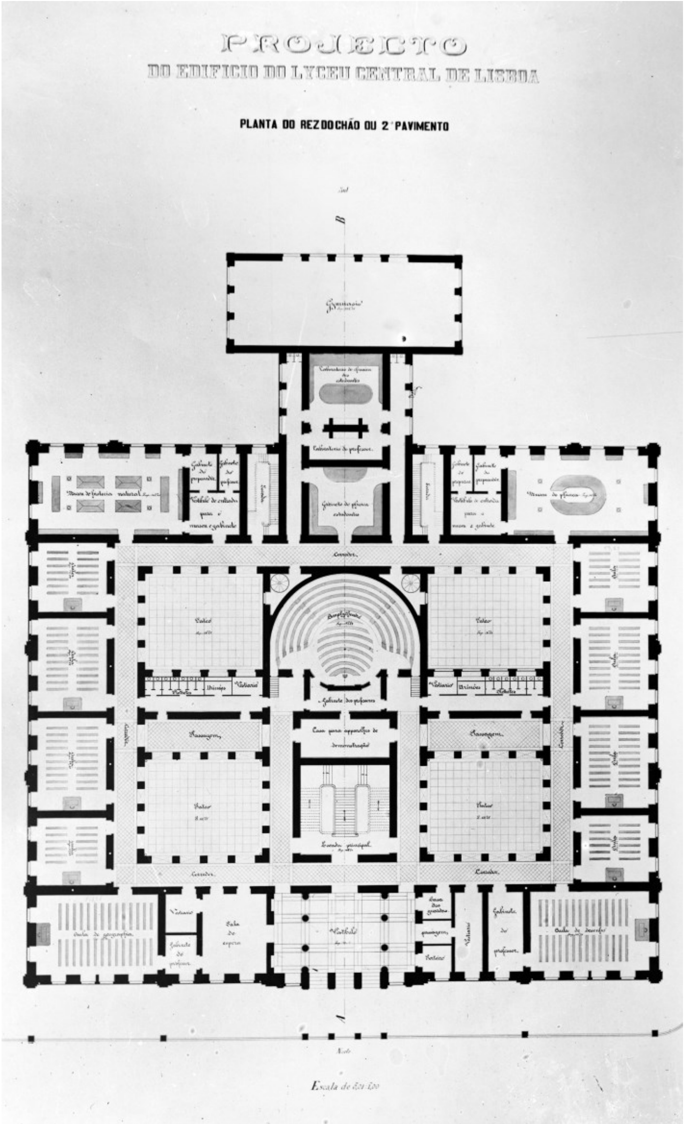

Figure 2.17 – Plan of "Liceu" Passos Manuel (Public domain)

From the analysis of the plan of this "Liceu", the following programme can be identified:

1. Amphitheatre with adjoining teachers' office ("Gabinete de professores") and room for demonstration equipment ("Casa para apparelhos de demonstração");
2. Museum of Natural History, with adjoining Preparer room ("Gabinete do preparador"), Teacher's office ("Gabinete do professor") and access chamber ("Vestíbulo de entrada para o museu e gabinete");
3. Cabinet of Physics for students ("Gabinete de physica estudantes");
4. Chemistry laboratory for students ("Laboratório de chimica dos estudantes") with adjoining Chemistry laboratory for the teacher ("Laboratório do professor");
5. Museum of Physics ("Museu de physica") with adjoining Preparation cabinet ("Gabinete de preparar") and Preparer cabinet ("Gabinete do preparador").

Laboratories

The Chemistry laboratory ("Laboratorio chimico" and "aula de chimica") was projected above the gymnasium, relatively isolated from the crowded main building in its south side and above the courtyard, with easy and direct communication with that same building from both the outside and the inside (CSOPM, 1907, p. 19).

Figure 2.18 – Chemistry lab, "Liceu" Passos Manuel (2007)

Amphitheatre

The Large Classroom, or Room for bright projections, was used as a large conference room or for demonstration lessons, with bright projections, disposed in a semicircle to accommodate 200 people. It was served by an elevator from the basement, to transport objects from the school museums (CSOPM, 1907, p. 22).

Figure 2.19 – Amphitheatre in “Liceu” Passos Manuel, with detail of fume cupboard (2007)

Cabinets and museums

The cabinets and museums provided collections with zoological, botanical, geological and mineralogical exemplars, associated with a historical-naturalistic approach of the curriculum based on classification (Gomes, 2014, p. 141). These exemplars were common in the “Liceus” before the Republic, in more than 70 % according to data gathered by Gomes (2014). The acquisition of educational resources more broadly for scientific subjects was one of the concerns of the consulting bodies of the 1895 government (CSIP, “Conselho Superior de Instrução Pública”). The list organised by this body in 1854 had an important impact on the structure of the “Liceus”' collections.

Matias de Carvalho e Vasconcelos, the Reader of the University of Coimbra, inventoried and budgeted a list of essential equipment for Science classes, in the case to the Hachette House in Paris. This list became a reference for the remaining “Liceus” (Gomes, 2014, p. 127-128), with some of these receiving the material through the “Ministério do Reino” or acquiring it through their own means (p. 132).

Figure 2.20 – Natural Sciences Cabinet, “Liceu” Passos Manuel

Figure 2.21 – Museum of Natural History, “Liceu” Camões

Between 1906 and 1928, according to Gomes, a profound shift in the concept of practical lesson took place. This shift can be seen in the changing materiality of the “Liceus”, with microscopy equipment, dissection, projection, chemical products, material for geological analysis and equipment for physiology experiments included in inventories of the time. In the international scene, concern grew with the pedagogical aspects of Science Education, with less emphasis on scientific content and more emphasis on student inquiry (e.g., “trabalhos individuais educativos”, or individual educational assignments). This change in Portugal gave more relevance to the laboratory rather than to the museum, at least if we look at the “Liceus”’ inventories (Gomes, 2014, p. 163).

2.5.2 The 1930s modernist "Liceus" – The case of "Liceu" Diogo de Gouveia

In 1918, a new commission is nominated to reform secondary education, balancing humanistic, scientific-utilitarian and artistic goals. Libraries and cinema rooms are considered in the building programme, and whenever possible, a gymnasium, a swimming pool and dressing rooms. In 1926, following the military dictatorship regime, the separation of female and male schools is enforced.

In 1928, and under a military dictatorship, Duarte Pacheco creates the "Junta Administrativa do Empréstimo para o Ensino Secundário" (Administrative Board for the Loan for Secondary Education, JAEES, 1928-1934), with a budget of 40.000.000 escudos from a government loan, to lead, among others, the construction of "Liceus" Maria Amália Vaz de Carvalho and Alexandre Herculano, previously interrupted during the Republican regime, and organize the call for projects for the "Liceus" of Beja, Coimbra and Lamego (1929-1931) and to equip with didactic material, furniture and weather stations the remaining "Liceus" (Parque Escolar, 2010, p. 21). The funding ran out in 1937.

The calls for architecture proposals take place in 1930, becoming an opportunity for the JAEES to produce a set of documents that functioned as a model programme. These documents included the General conditions establishing the rules for creating the architecture project, which included the Special conditions and the Bases for the construction of "Liceus" (Acabamentos / "Finishings"), which the proposals should follow. In the case of Science, there was a functional group dedicated to Science teaching, with Chemistry, Physics and Natural Sciences laboratories (Alegre, 2009, pp. 237-238).

"Liceu" Diogo de Gouveia, in Beja, a project by architect Cristino da Silva inaugurated in 1937, has two perpendicular axes with three distinct bodies, around an outdoor courtyard. The Modern Movement is manifested in this construction project, together with the remaining "Liceus" of the plan, using new materials such as reinforced concrete and pure geometrical volumes without decorative elements. The lettering Art Deco above the main entrance is also representative of the movement.

In the north body, the ground floor is accessed through a lobby that separates the rectory services from the Natural Sciences classrooms. In the general conditions are mentioned Physics, Chemistry and Natural Sciences laboratories, a greenhouse and an aquarium, and on the outside, land for the preparation of exemplars for experiments and studies (Alegre, 2009, pp. 242-243).

Typology of spaces

The typology of Science spaces in this "Liceu" is (Nóvoa & Santa-Clara, 2003, p. 106):

1. Amphitheatre;

2. Physics cabinet;
3. Chemistry cabinet;
4. Natural Sciences cabinet;
5. Natural Sciences museum;
6. Aquarium;
7. Greenhouse.

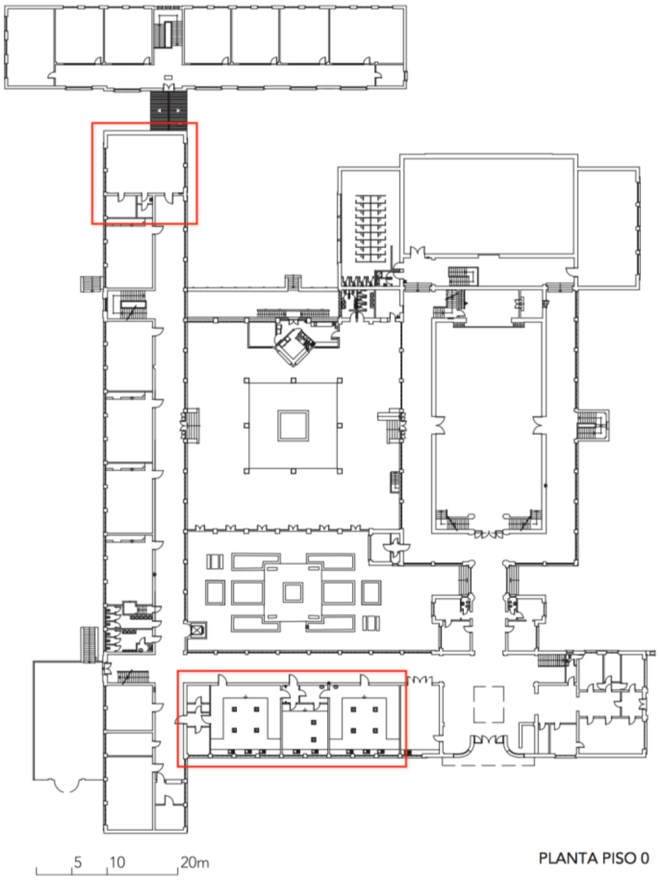

Figure 2.22 – "Liceu" Diogo de Gouveia building plan, ground floor (Parque Escolar, 2010, p. 163)

From the analysis of the building plan, in which the spaces for Science are identified, several annexes are associated with the main spaces.

Figure 2.23 – Natural Sciences cabinet, “Liceu” Diogo de Gouveia (DGPC, n.d.)

Figure 2.24 - Physics cabinet, “Liceu” Diogo de Gouveia (Parque Escolar, n.d.)

Figure 2.25 – Chemistry laboratory, “Liceu” Diogo de Gouveia, 1930s (Nóvoa & Santa-Clara, 2003, p. 113)

2.5.3 The plan of 38 – The case of "Liceu" Sá da Bandeira

In 1934 the JAEES is replaced by the "Junta das Construções para o Ensino Técnico e Secundário" (Board of Constructions for Technical and Secondary Education, JCETS, 1934-1969). Following the secondary education reform of 1936 and the construction, extension and improvement project of the "Liceus" of 1938 led by JCETS (the Plan of 38), 10 new "Liceus" were built and others were intervened:

1. "Liceu" Nuno'Alvares, mixed, in Castelo Branco;
2. "Liceu" of Chaves (not built);
3. "Liceu" Infanta D. Maria, for girls, in Coimbra;
4. "Liceu" João de Deus, in Faro;
5. "Liceu" D. João de Castro, mixed, in Lisbon;
6. "Liceu" Gil Vicente, for boys, in Lisbon;
7. "Liceu" Carolina Michaelis, for girls, in Oporto;
8. "Liceu" Sá da Bandeira, mixed, in Santarém;
9. "Liceu" Gonçalo Velho, mixed, in Viana do Castelo;
10. "Liceu" Alves Martins, mixed, in Viseu.

The intervened "Liceus" were Maria Amália Vaz de Carvalho, in Lisbon, and Alexandre Herculano, in Oporto, and the conversion of the primary school of "Bairro do Arco Cego", in Lisbon, to "Liceu" D. Filipa de Lencastre (Alegre, 2009, p. 253). This effort was not enough due to the increase in the number of students that tripled in the 1940s (Parque Escolar, 2010, p. 23).

The "Estado Novo" regime began in this plan an uniformization of the architectonic and urbanist language of these buildings, serving historicist and nationalistic ideals into a monumental architecture.

"Liceu" Sá da Bandeira, in Santarém, a project by architect José Costa e Silva, inaugurated in 1943/44. In 1941, in the report "Relatório dos trabalhos realizados – 1940" (Report of the completed works – 1940), the "Programa Geral para a Elaboração dos Projectos dos Liceus" (General Programme for the Development of "Liceus"' Projects) is first set, to implement in the new "Liceus", establishing the nature and features of the several services, organised into groups, enforcing the separation of genders. From the entrance hall is guaranteed access to all classrooms and special spaces, through lateral corridors that structure the entire building, in a linear typology (Alegre, 2009, p. 256).

Typology of spaces

The spaces dedicated to Science teaching and learning of "Liceu" Sá da Bandeira are included on the 2nd floor (JCETS, 1940):

1. Museum;
2. Amphitheatres;
3. Physics Laboratory;
4. Scales' cabinet;
5. Dark chamber;
6. Physics material deposit;
7. Optics cabinet;
8. Annex;
9. Chemistry material deposit;
10. Preparation cabinet;
11. Chemistry lab.

Amphitheatre

The amphitheatre serves experimental classes and sessions, being adequate for projections and experimental demonstrations in Physics, Chemistry, etc. made by the teacher. The dimensions were be at least those of a regular classroom. The relationship between the room area and the lighting surface was between 1/5 and 1/6. Steps were made of wood, with waterproof floor and ceilings in plaster.

The teacher demonstration table was served by water, gas and sink. For 2nd cycle sessions, it had a preparation room attached.

Figure 2.26 – Amphitheatre of "Liceu" Sá da Bandeira (Parque Escolar, n.d.)

Chemistry laboratory

The Chemistry lab had space for practical activities in Chemistry, for half class (18 students) with an area of approximately 80 m^2. The floor was waterproof and the walls and ceiling in plaster, with the same lighting conditions of a regular classroom. Associated with the lab, there were two rooms: a preparation cabinet and the material' storage room.

The lab benches provided water, gas and sink.

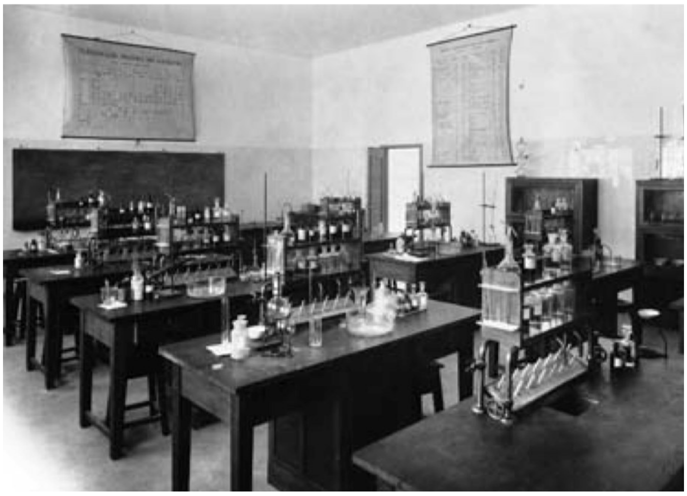

Figure 2.27 – Chemistry lab, "Liceu" Sá da Bandeira (Parque Escolar, 2010, p. 168)

Physics laboratory

The Physics lab had space for practical activities in Chemistry, for half class (18 students) with an area of approximately 80 m^2. The floor was waterproof and the walls and ceiling in plaster, with the same lighting conditions of a regular classroom. Associated with the lab, there were four rooms: a preparation cabinet, the material deposit, the scales cabinet and the dark room.

The lab benches provided water, gas and sink.

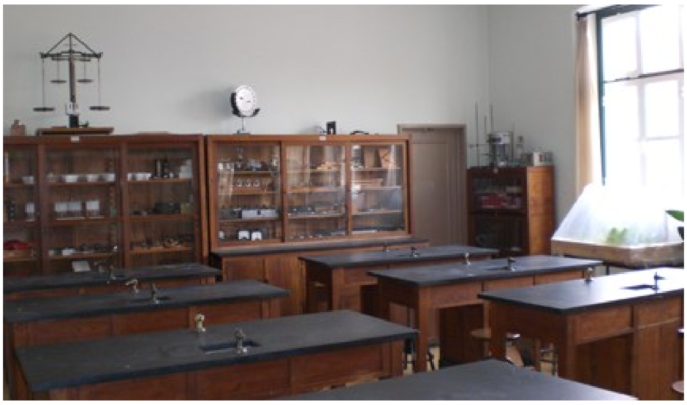

Figure 2.28 – Physics laboratory, “Liceu” Sá da Bandeira (Parque Escolar, n.d.)

Geographical-Natural Sciences Classroom

Associated to this classroom was a space for storing the material of the subject. The area was approximately 80 m^2.

Material deposit

The deposit had space for storing material for teaching used in the lesson, with an area of 50 m^2.

Furniture

The furniture of the Physics and Chemistry Laboratories included students’ practical work tables (M30 in Physics and M13 in Chemistry), teacher’s table (M12), Washing module (“escoadouro”, M28) and a notebook cabinet.

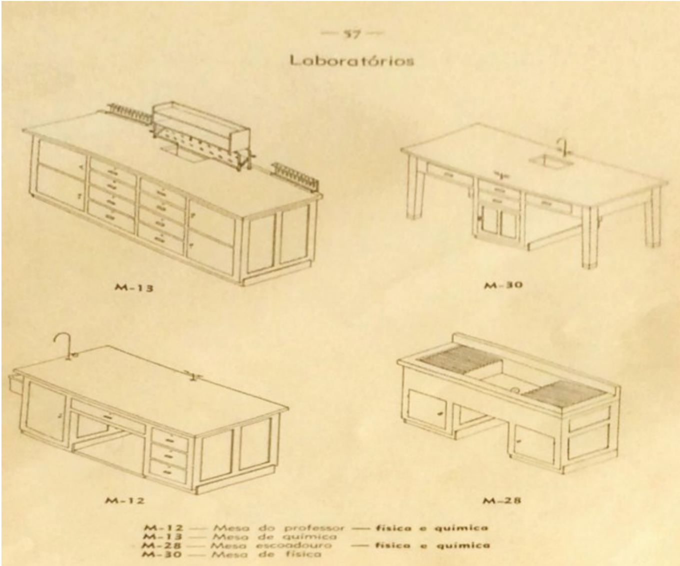

Figure 2.29 – Drawings of laboratory furniture modules (JCETS, 1940, p. 57)

2.5.4 The plan of 1958 – The case of "Liceu Nacional de" Cascais

In 1958, a building project for 16 new "Liceus" in 8 years is led by JCETS, that will later benefit from the knowledge and practices achieved by the "Grupo de Trabalho sobre Construções Escolares" (Working Group on School Construction, GTSCE) during the 1960s in the standardization of the production plan (planning, programming, conception and construction) in general norms, applicable to in this case, the "Liceus". These "Liceus", built during the 1960s and until 1969, are however architectonically heterogenous, such as:

1. "Liceu" Rainha D. Leonor, Lisbon;
2. "Liceu" Padre António Vieira, for boys, Lisbon;
3. "Liceu Nacional de" Cascais;
4. "Liceu" D. Pedro V, mixed, Lisbon;
5. "Liceu" Garcia de Orta, Oporto;
6. "Liceu" Santa Isabel, Oporto;
7. "Liceu" Martins Sarmento, Guimarães;
8. "Liceu de" Évora, for girls;
9. "Liceu" D. Duarte, Coimbra;
10. "Liceu" Heitor Pinto, Covilhã;
11. "Liceu" Infante de Sagres, Portimão;
12. "Liceu" Bissaia Barreto, Figueira da Foz;
13. "Liceu" D. Maria II, for girls, Braga;

14. "Liceu" Emídio Garcia, Bragança;
15. "Liceu" Afonso de Albuquerque, Guarda;
16. "Liceu de" Viseu, for girls.

This plan was later extended to "Liceu Nacional de" Angra do Heroísmo, "Liceu Nacional de" Cascais and "Liceu de" Vila Nova de Gaia (Alegre, 2009, p. 263).

The 2nd normalised project for the "Liceus" of Cascais and Vila Nova de Gaia, developed in 1964 by architect Augusto Brandão from JCETS, establishes a new organisation of the school spaces, integrated into pavilions, marking a shift in previous practices. Active learning pedagogies imply active spaces, and in this sense, common spaces for learning activities beyond the classroom, open to the community, are included in the overall design, such as the library, museum and social spaces in each pavilion, to where classrooms converge, eliminating circulation corridors and a linear distribution of the buildings. A central school block and the remaining blocks, in a total of 6, the so-called pavilions, are linked by communicating galleries.

The classroom was also redefined, becoming squared, allowing different configurations of furniture and students. The furniture becomes more mobile, light and stackable, with two boards in facing walls, allowing strategies beyond the teacher-centred ones. The platform for the teacher area was envisioned for student activities such as students' plays and short dialogues. There were considered also exhibition areas and shelves below the windows to store students' works and an open cupboard for a small library.

Two blocks were dedicated to the teaching of 2nd and 3rd cycles, having besides the regular classrooms, laboratories, amphitheatres and classrooms for the geographical-natural Sciences. Pedagogical kitchen gardens were also proposed, and the overall increase in the number of laboratories to the detriment of amphitheatres, considered as spaces for passive learning in the words of Augusto Brandão (Alegre, 2009, p. 265).

Typology of spaces

Some of the spaces related to Science will be briefly described, from a visit to "Liceu Nacional de" Cascais in 2016, one of the exemplars of the plan of 1958:

1. Amphitheatre;
2. Physics laboratory;
3. Preparation room;
4. Dark room;

5. Storage area;
6. Chemistry laboratory;
7. Preparation room;
8. Chemical storage room.

Amphitheatre

The amphitheatre had a fixed demonstration bench for the teacher, serviced by gas. A large writing board occupied the wall closer to the teacher. Four fixed benches per row, in a total of 5, accommodated between 40 and 60 students. There were also 20 honeycombs below the windows for storage and a wooden cupboard.

Figure 2.30 – Amphitheatre, “Liceu Nacional de” Cascais (2016)

Physics laboratory and preparation room

The Physics laboratory had 5 rows of two movable benches, with 4 central fixed modules serviced by water and gas. The countertops were made of stone. Below the windows, there was a fixed shelf along the room with cupboards underneath with sliding doors. The opposite wall was filled with wooden cupboards with sliding transparent doors, with windows above.

In the wall closer to the teacher, there was a chalkboard, and in the opposite wall, a washing module and a cupboard with transparent doors. On the left, there was access to one of the annexes, that included a dark room, and on the right, a door to an attached cabinet with a fixed bench on two of the walls, with the remaining space filled with cupboards.

Figure 2.31 – Physics laboratory, "Liceu Nacional de" Cascais (Alegre, 2009, p. 279, left, and 2016, on the right)

Figure 2.32 - Physics prep room and dark chamber, "Liceu Nacional de" Cascais (2016)

Chemistry laboratory and preparation room

The Chemistry laboratory is mostly like the Physics laboratory except in the following aspects:

1. In the wall, close to the teacher, there was a fume cupboard with ventilation;
2. In the wall opposite that of the teacher area, there was a fixed bench occupying the entire wall;
3. The annex on the left was smaller, dedicated to the storage of chemicals, and the annex on the right was larger, with three fixed side benches.

Figure 2.33 - Chemistry laboratory, “Liceu Nacional de” Cascais (2016)

Figure 2.34 – Chemistry prep room, “Liceu Nacional de” Cascais (2016)

2.5.5 The Model “Liceus” of 1968 – The case of “Liceu” Nacional de Almada

The III “Plano do Fomento” (Development Plan) defined the construction of 11 new “Liceus” across the country. The construction of Preparatory Schools for Secondary Education following the reform of 1967, involved the creation of a team led by Augusto Brandão that defined a Model project for these schools. Architect Maria do Carmo Matos, at the same time, led a study on the “Projecto Normalizado para Liceus-Tipo” (Normalised project for Model “Liceus”), supported by new pedagogical views, new construction systems and building materials that reduced construction time and costs due to the repetition of elements and easy adaptation to different terrains. (Alegre, 2009, pp. 284-285)

The B block was destined to laboratories, considering Physics and Chemistry labs, classrooms for Natural Sciences, Geography, Mathematics and a common amphitheatre to all subjects. These spaces were distributed by two floors, organised around an exterior courtyard. Two independent entrances allowed access to a small transition space, avoiding a circulation corridor. This integration of specialised spaces reduced costs due to the savings in the servicing infrastructure. (Alegre, 2009, p. 286)

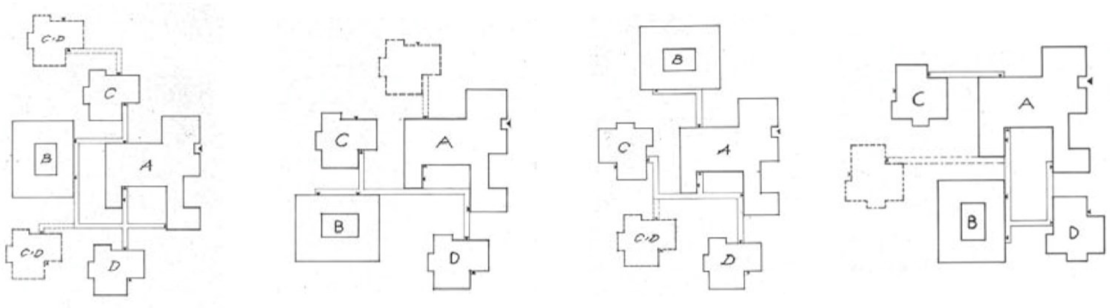

Figure 2.35 – Different organisations for the pavilions in the normalised project for the model "Liceu" (Alegre, 2009, p. 284)

In the B block took place the most technically specialised activities, demanding from the student the observation of natural phenomena. The main functions of this block were the theoretical teaching of Science (Physics, Chemistry, Natural Sciences, Mathematics, Geography), the practical teaching of Science, investigations by teachers and students, photography and conferences. (MOP, 1968)

The typology of spaces of the B block is (MOP, 1968):

1. Two classrooms for the theoretical and practical teaching of Physics;
2. Two classrooms for the theoretical and practical teaching of Chemistry;
3. Two classrooms for the theoretical and practical teaching of Natural Sciences;
4. Four classrooms for the theoretical and practical teaching of Mathematics;
5. One classroom for the theoretical and practical teaching of Geography;
6. One laboratory for the teaching of Physics and attached cabinet;
7. One laboratory for the teaching of Chemistry and attached cabinet;
8. One laboratory for the teaching of Natural Sciences and attached cabinet;
9. One amphitheatre;
10. Cabinet for meetings for the teachers of the block;
11. Two dark rooms;
12. Annexes – storage of didactic equipment, workshops for repair of equipment.

Chemistry laboratory and preparation room

Fixed benches on the side serviced by a washing module were observed in the labs, with storage modules below and shelves above. The central area was occupied by fixed benches for students, serviced by water. A fume cupboard occupied the front of the lab, together with a board, with storage modules below. The prep room had a fixed side bench with storage modules below.

Figure 2.36 – Chemistry laboratory, fume cupboard and preparation room, ES Fernão Mendes Pinto, previously "Liceu de" Almada (2007)

Physics laboratory and preparation room

The Physics lab did not include a fume cupboard. In the remaining aspects, it was similar to the Chemistry lab.

Figure 2.37 - Physics laboratory, entrance to dark room and preparation room, ES Fernão Mendes Pinto, previously "Liceu de" Almada (2007)

Science classroom

The Science classroom had a rectangular format with a fixed bench for the teacher serviced by water and electricity. On the window side, there was a fixed bench serviced by water, with cupboards underneath for storage. Some of the storage modules had drawers.

Figure 2.38 – Science classroom, ES Fernão Mendes Pinto, previously "Liceu de" Almada (2007)

2.5.6 Projects by the Regional Directorates of Education

By the end of the 1970s, there was again an expansion in the construction of schools led by an ever-growing school population. One team led by architect Maria do Carmo Matos and engineer Victor Quadros Martins develops, in the "Direcção-Geral para o Equipamento Escolar" (Directorate General for School Equipment, dGEE), now under the Ministry of Education (ME), the "Estudo Base para a Elaboração dos Projectos de Execução de Instalações para Escolas Preparatórias e Secundárias" (Base Study for the Preparation of Projects for the Execution of Installations for Preparatory and Secondary Schools, EPI-2) (1976-77). This study defined the model for the spaces' programming and a school typology by level of education and number of students, based on industrial construction to lower costs and project duration. In 1978, the Directorate General for School Construction, under the Ministry of Public Works, developed the concept of "Família de Soluções" (Family of Solutions), to be applied in the design of Preparatory and Secondary schools. In the beginning of the 1980s, besides the School Construction Special Plans, using industrialised construction techniques, a new Model project called 3 × 3, compact or mono-block integrates prefabricated elements. And from 1986, with the publication of "Lei de Bases do Sistema Educativo" (Law n. 46/86, October 14), the Ministry of Education assumes the responsibility for constructing schools, delegating it to the Regional Directorates of Education, that apply the accumulated knowledge in the new schools. (Parque Escolar, 2010, pp. 32-33)

In these projects, the typology of spaces was the following (DGAE, 2001):

1. Chemistry lab;
2. Physics lab;
3. Biology and Geology lab;
4. Locker room;
5. Preparation and storage rooms, with specific area for chemical products;
6. Scales room;
7. Dark room;
8. General Sciences classroom;
9. Annex to the general Sciences classroom;
10. "Biotério" (space dedicated to raise and care for animals).

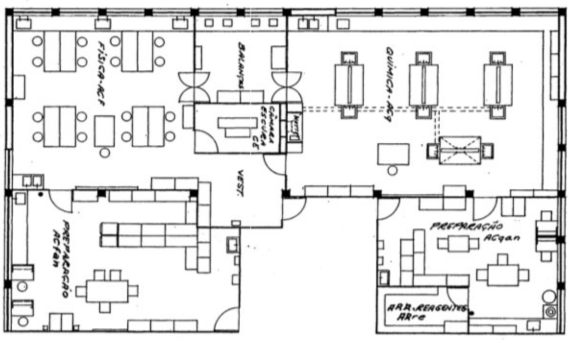

Figure 2.39 – Chemistry and Physics laboratories and annexes (DGAE, 2001, p. 134)

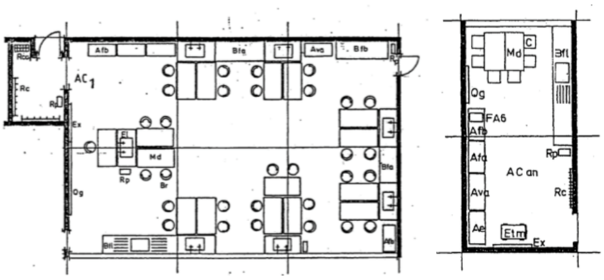

Figure 2.40 – General Sciences classroom and annex (DGAE, 2001, pp. 125-126)

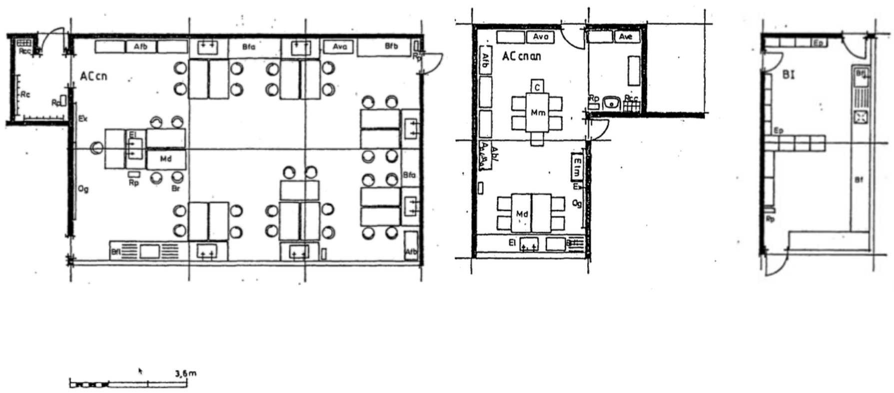

Figure 2.41 – Biology and Geology laboratory, annexes and "biotério" (DGAE, 2001, pp. 127-129)

Secondary School Anselmo de Andrade opened in the school year of 1986/1987 after a construction project led by the Regional Directorate of Education of Lisbon and the Tagus Valley (DRELVT). In the next section, some of the spaces are briefly presented.

Figure 2.42 – Chemistry laboratory, preparation room and scales' room, ES Anselmo de Andrade, Almada (2015)

Figure 2.43 – Biology and Geology laboratory, preparation room and group room, ES Anselmo de Andrade, Almada (2015)

2.5.7 The Parque Escolar EPE secondary schools' buildings modernisation project - the Science Learning Studio

As already mentioned in the introductory chapter, Parque Escolar initiated a secondary schools' buildings modernisation project, with an intervention in the Science spaces. A consultancy work to Parque Escolar EPE beginning in 2008, led by Prof. Vitor Duarte Teodoro and in which I participated, supported the design of this model, later applied to 106 schools by 2011, and still expanding in 2017. In this section, this model will be briefly described, particularly its development.

The challenge – a flexible space for diverse learning programmes, economically sound and adaptable to multiple school configurations

The key element of the proposed model, the pair of laboratories with a shared prep room in between, what I call Science Learning Studio, faced several design challenges, from financial restraints in the options taken (manifested in the required infrastructure for example) to limitations of the industry in providing certain solutions (e.g., the teaching wall, developed specifically for the model), or choices not in the control of the programme (e.g., Technological Plan of Education, with a closed setup of technological solutions for every school, prior to the PE initiative). Above all, the model needed to be sufficiently flexible for diverse learning programmes and adaptable to multiple school configurations, which spanned almost 100 years of diverse school building programmes (first "Liceus", plans of 1938, 1958, 1968) and different types of schools ("Liceus", Technical Schools, Industrial Schools, Model Projects, 3 × 3 Blocks, etc.).

The vision underlying a new model of school Science spaces

The new concept for Science spaces was created based on a vision of Science education that has as its main goals (Fernandes et al., 2009, pp. 7-8):

1. Make epistemic and human aspects of Western Science more accessible and relevant to students, exploring the ways in which scientific knowledge is obtained, verified and refined, as well as the processes, values and implications of this knowledge. Ethnicity, language, culture, gender and socio-economic level should be considered (Duschl et al., 2007);
2. Help students become better critical thinkers, creative problem solvers, and especially best decision-makers in their daily lives related to Western Science and technology, with a particular emphasis on the use of evidence, argument and dialogue;

3. Increase the capacity of students to communicate with scientific and technological communities and with representatives of the media;
4. Increase the involvement of students in practices of social responsibility (citizenship), seeking social justice and socio-political action;
5. Increase the interest and success in learning of canonical content found in traditional curriculums, seeking depth, consistency and relevance to everyday life (Millar & Osborne, 1998, Aikenhead, 2006, Osborne, 2007, Reiss, 2007).

To achieve these goals, students work actively to build personal knowledge that is shared, actively explore Nature and test ideas and models, conduct long-term investigations, get involved in conversations on natural phenomena, reflect and discuss impacts on Society and Nature, collect, analyse, create and share information not only on Science but also in a multidisciplinary and interdisciplinary perspective. The SLS should support these activities, and:

1. Hands-on, minds-on, hearts-on diverse teaching strategies (Sunal et al., 2007; Wagensberg, 2001; Rocard et al., 2007, Duschl et al., 2007) departing from students' prior knowledge (National Research Council, 2005);
2. The use of technology as a tool to "think with" and that can extend the sense of community, access to information, communication, collaboration, modelling and creation (Papert, 1980, Senge et al., 2005, Teodoro, 2002, Michaels et al., 2008);
3. Integrated assessment, aligned with the vision of the curriculum, including self-assessment, peer review and reflecting real life evaluation processes (Lombardi, 2007);
4. A strong and transparent connection with the school and community, with sustained collaborations and finished products (multiple and competing) created by students, and that can impact both. Learning also occurs outside the classroom and in informal environments (Lombardi, 2007; Tilling & Dillon, 2007, Osborne & Dillon, 2008);
5. The schedules and access to tools are aligned with the vision of the curriculum and support the work of teachers and students (Beichner et al., 2007).

Developing a new model

The methods used in developing the model of Science learning spaces for the modernisation programme were (Fernandes et al., 2009):

1. Analysis of the current situation in schools' Science laboratories (White Paper on Physics and Chemistry, Diagnosis of spaces for Experimental Sciences, visits and photos of schools);

2. Visits to international schools and Science teachers' training centres (Finland, Sweden, Science Learning Centres in the UK);
3. Historical analysis of several existing laboratory models, nationally and internationally;
4. Literature review on environment-behaviour, design of spaces for learning, teaching and learning of Science and technology in Science learning;
5. Consultation of technical documentation from other countries on designing spaces for learning, in particular Science learning spaces;
6. Benchmarking of solutions and models adopted abroad, such as the Faraday Project and Science Learning Centres, in the UK, Laboratory 21 in Ireland and SCALE-UP in North Carolina State University;
7. Visits to thematic exhibitions on educational technology fairs (e.g., BETT Show 2008, Building Schools Exhibition and Conference 2008, UK);
8. Web and catalogue search for suppliers and market solutions, nationally and internationally;
9. Consultations with teachers and students (of various levels of education and schools);
10. Consultation with industry (furniture, equipment, ICT, waste management);
11. Consultations with researchers of scientific areas related to Physics, Chemistry, Biology, Geology, Microbiology, Waste Management;
12. Analysis of the Science curricula of secondary education and school textbooks, in particular the proposed activities and required resources;
13. Analysis of schools' Science department inventories;
14. Analysis and discussion of a "Ciência Viva" proposal (2007) for alternative schools' Science spaces model for the Parque Escolar's rebuilding programme;
15. Review of the legislation on safety, building regulations, laboratory technicians;
16. Definition of budget constraints, market and mass application to the national context;
17. Prospective analysis;

The main principles behind the choices made for the design elements of the SLS were the following (Fernandes et al., 2009):

1. Increase in the number of spaces of this kind per school, so that all Science lessons can take place in the SLS, theoretical, practical and with diverse teaching programmes;
2. The flexibility of arrangement and functionality to allow a diversity of teaching strategies and students' active learning, from reception learning to practical activities, open enquiry, project-based learning, etc.

3. Adequate storage areas, to facilitate access to scientific equipment, chemicals and materials and circulation of teachers and students;
4. Transparency in both space and furniture to facilitate visual control, observation and identification of material and equipment;
5. ICT readiness, adapted to technologies supporting diverse activities;
6. Lived spaces, exhibiting scientific equipment of historical value, rare models and students' work;
7. Large collaboration areas for groups of students;
8. Safety first, to prevent or provide adequate responses to accidents.

Proposed design elements

The principles guiding the model manifested in the proposed design elements:

1. Areas large enough to accommodate half or the full class;
2. High benches for use while seated or standing, with a surface area large enough for groups of up to three students and resistant to impact, fire and most chemicals;
3. Stools with height adjustment, capable of being stored bellow benches if necessary to free space of circulation and work;
4. Movable benches to allow reconfiguration according to the type of activity;
5. Large teaching wall to support not only teacher work but also collaboration between students. On top, space for exhibiting historical scientific equipment and behind the sliding doors, space providing generous storage;
6. Honeycombs to store students' bags and jackets and unclutter the working space;
7. Electricity and water sinks on the side benches, with the same height than the movable benches to minimise infrastructure costs, extend the bench area with movable benches if necessary, facilitating students' work towards the teacher with access to both electricity and water;
8. Washing modules in both prep room and labs, to facilitate washing by students if required;
9. Shared prep room between two labs to accommodate shared resources and resources not accessible to students, chemical products cabinet with ventilation, flammables' cabinet, etc.;
10. Transparent walls between prep room and laboratory and transparent doors to facilitate visual control of students by the teacher, observation of lessons by other students and mutual teacher observation;
11. Shelves for placing materials and equipment to support practical activities or exhibiting students' work;

12. Transparent storage modules to facilitate visual identification of materials and equipment;
13. Transparent boxes acting as drawers to facilitate organisation and transportation of materials and equipment from and to the storage modules;
14. Trolleys to organise kits of activities in trays and facilitate transportation from and to the prep room;
15. Adequate safety equipment and waste management.

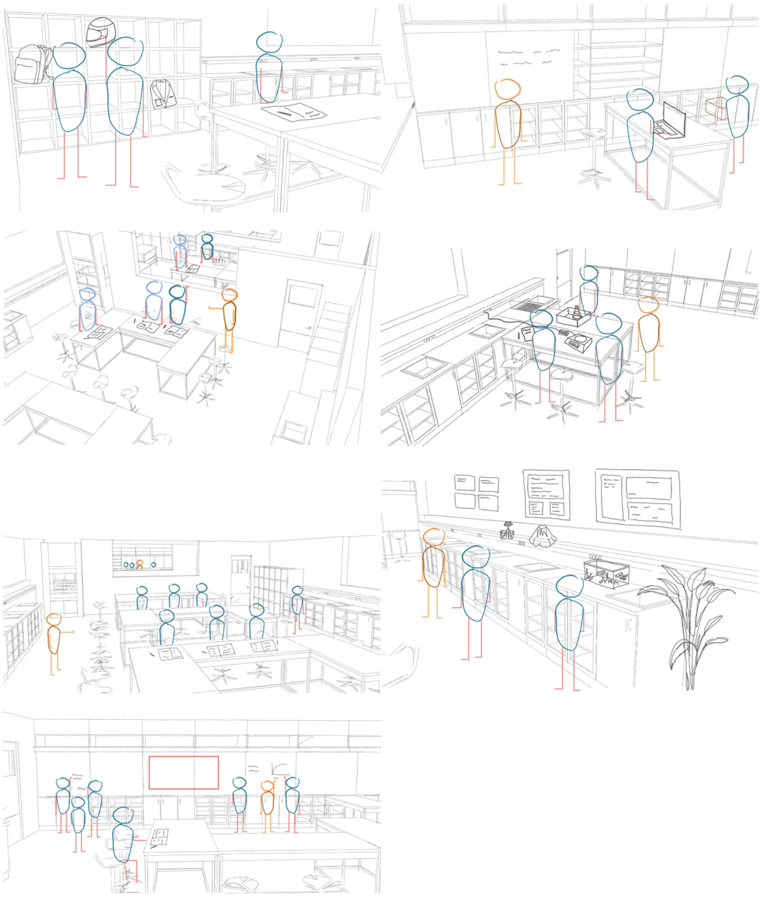

Figure 2.44 – Some illustrations of the Science Learning Studio

Participatory design

During the development stage of the model, public discussions were held with teachers, architects and experts beginning in September 27, 2007, in a brainstorming format, first in Parque Escolar headquarters, in Lisbon, later in an online forum http://ctne.fct.unl.pt/mod/page/view.php?id=2560, followed by several publications in "Gazeta da Física" (Physics Gazette), the magazine of the "Sociedade Portuguesa de Física" (Portuguese Society of Physics, Heitor et al., 2007; Heitor et al., 2008; Abreu, 2008), with replies by the Science education community. On June 26, 2008, in FCTUNL, we organised an open working day with Science teachers, to discuss the document setting the key features of the new model and the initial version of the website http://laboratoriosescolares.net, to support further discussion and share useful resources with teachers, students, technicians, head teachers and the community. After the 4 pilot schools' openings in September 2008, a seminar took place for the Science Education community in Secondary School D. Dinis in Lisbon in February 2009, in Lisbon, with a visit to the new spaces in this pilot school, followed by visits of the team to the pilot schools to gather feedback and inform the next iteration of the model.

Applied design elements

Parque Escolar adapted the proposed model to the architectural project manual guiding the rebuilding program. In version 1 of this manual, the following reference diagram was presented for the SLS.

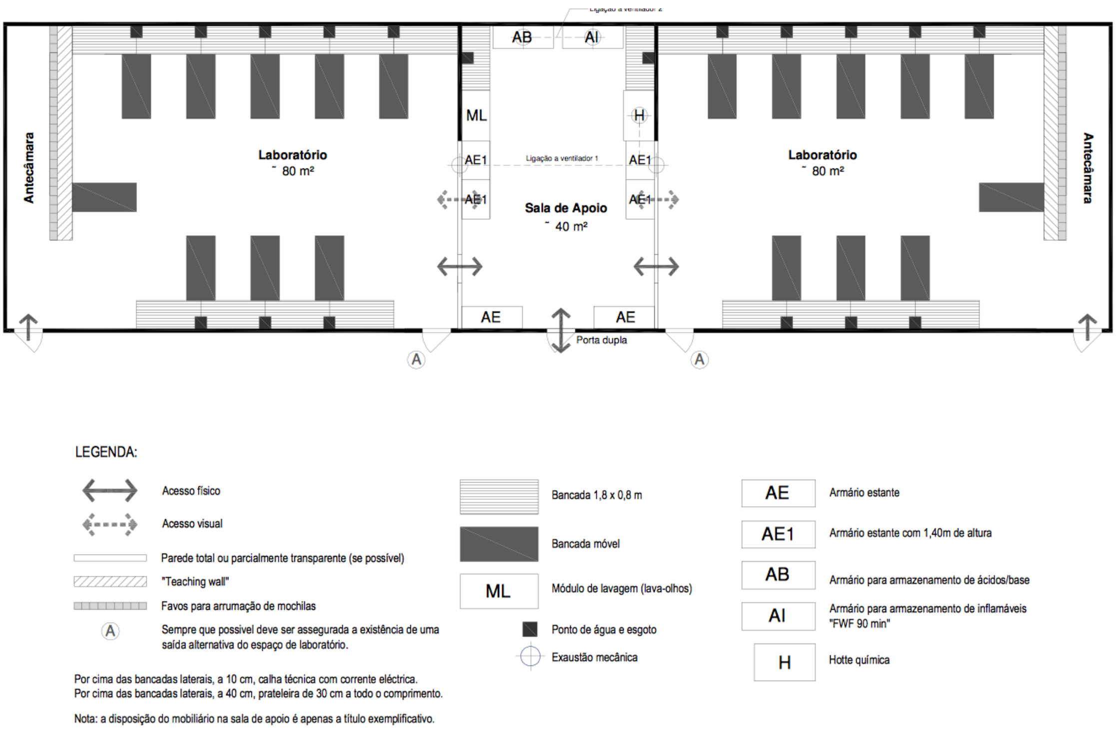

Figure 2.45 – Diagram for the schools' laboratories (Parque Escolar, 2008, p. 15)

The following indications were also given:

1. Areas: Laboratory 80 m² / Support room 30-40 m²;
2. Minimum height: 2.80 m;
3. Obstruction system for exterior windows and roller blind for windows between support room and adjacent laboratories;

4. Electrical panel near the entrance, preferably located on the wall behind the door;
5. Light coloured walls with impermeable finishing;
6. Anti-slip floor, resistant to major chemicals and impacts and easily washable;
7. Ceiling with acoustic treatment;
8. Entrance allowing viewing to the spaces;
9. Exit doors with opening in the direction of the escape route;
10. Walls between the laboratory and support room with visibility from 1.40 m and on 2/3 of the wall extension;
11. Teaching Wall - Cabinet with at least 0.60 m depth and 2.00 m in height, projectable, magnetic and writable, with sliding doors and 24 or more of 0.40 × 0.40 × 0.60 m honeycombs located behind the doors closer to the entrance (apply only in case of impossibility of antechamber);
12. Benches 1.80 m × 0.80 m for teacher and students, mobile and height adjustable;
13. Fixed side benches with 1.80 m × 0.80 m and 0.90 m in height;
14. A chamber to access the laboratories should be provided wherever possible;
15. Laboratory storage modules should have a master system so that there is only one master key to open all cabinets.

In version 2.1 of the manual several changes were introduced in the reference diagram.

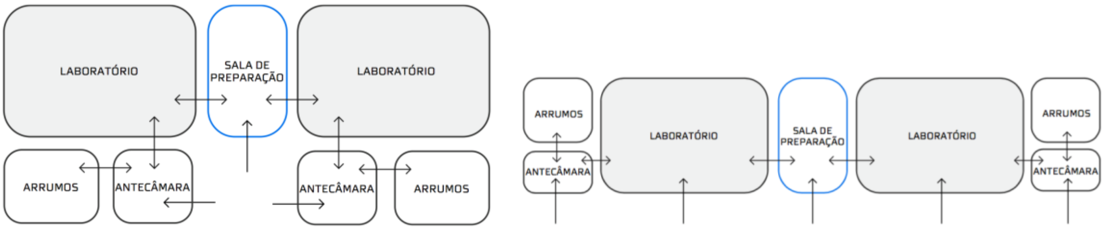

Figure 2.46 - Diagram for the schools' laboratories, compact (left) and linear (right) (Parque Escolar, 2009, pp. 58-59)

The entrance chamber and the storage area were the main changes in the diagram in the 2008 version.

Two plans providing an application of the diagram were also presented.

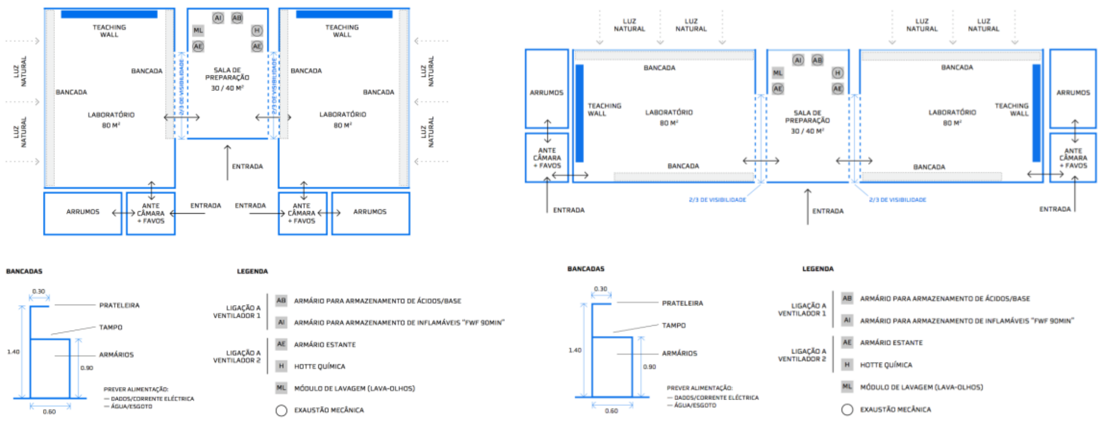

Figure 2.47 – Plans for the schools' laboratories by Parque Escolar, compact (left) and linear (right) (2009, pp. 58-59)

A 3D model of the spaces was also made available to facilitate interpretation by the project's teams:

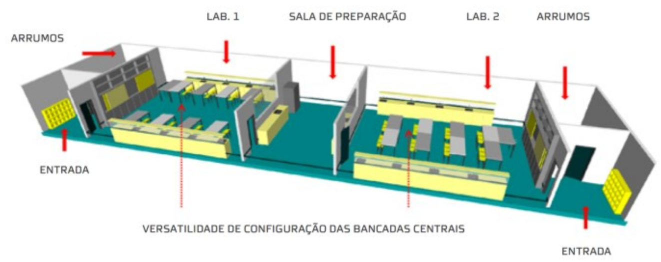

Figure 2.48 – 3D mode of the linear distribution of Science spaces (Parque Escolar, 2009, p. 60)

The following indications were also given (Parque Escolar, 2009, p. 57):

1. The laboratories preferably exist in pairs, wherever possible with a common support room in between, for shared equipment (e.g., chemicals cabinets, fume cupboard, etc.). If not possible, each laboratory shall have access in the same floor to a support room within a radius of 20 meters;
2. The laboratories and preparation room are classified as risk location A: "Flammable liquids in quantities not exceeding 10 litres" - Art. 10.º 2-b of Decree-Law no. 220/2008;
3. Whenever possible, visibility between the laboratories and the support rooms, from 1.40 m and 2/3 on of the wall extension;
4. The laboratories have a flexible spatial organisation with wide and movable benches (0.80 m × 1.80 m) for 3 to 6 students, which allow work standing or sitting;
5. The side walls have fixed benches with water points, technical gutter and shelf to the full extent (1.80 × 0.80 m and 0.90 m in height). Underneath the benches are storage cabinets, fitted with locks with a mastering system so that there is only one master key for all;

6. The movable benches allow different configurations and can be placed away from or next to the side benches in a quick and quiet way;
7. The surfaces of the side benches are resistant to the main chemicals and fire;
8. The interior of the fume cupboard is visible from any of its sides;
9. All laboratories have access to the Internet, computer and projector.

Supporting architects, technicians and industry in the development stages of the model

New building plans produced by the architects responsible for the rebuilding projects were commented by the team in PDF, and a checklist was made to support the work of architects, technicians and suppliers involved in construction and refurbishment.

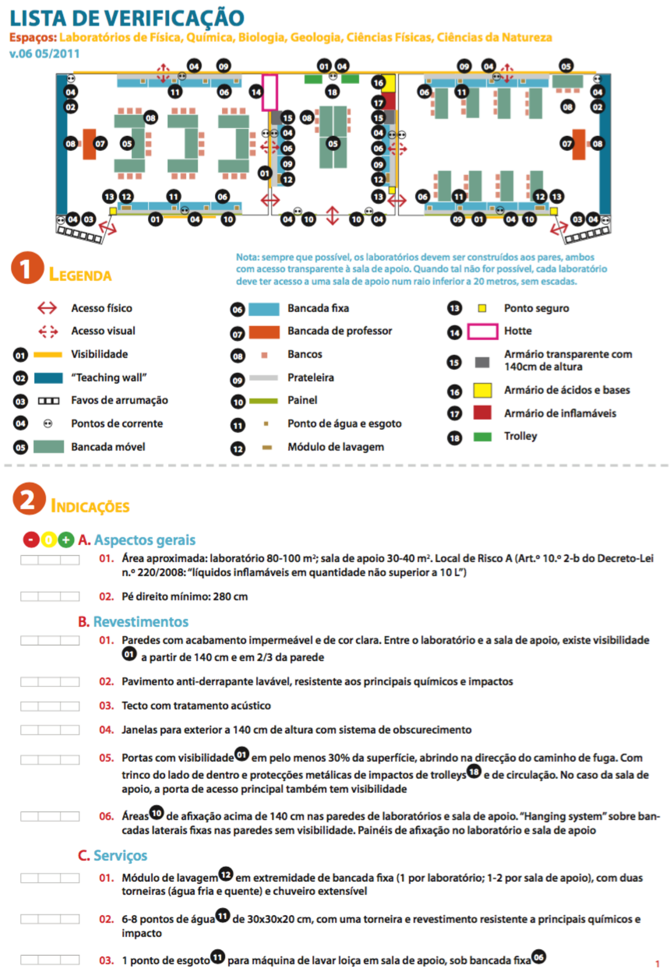

Figure 2.49 – Checklist for architects, technical teams and suppliers

There were several meetings with industry providers, testing, analysing current offers and developing new ones (e.g., stools, teaching wall, a double-access fume cupboard shared between the prep room and the adjacent lab, movable fume cupboards).

Visits to schools were also common, with meetings with the Science departments (Science teachers and heads of department, group and facilities) and the technical staff of Parque Escolar in schools involved in all phases of construction. These meetings were generally concerned with communicating to the school the rationale underlying the model, discussing specific needs and proposed changes by the department or gathering feedback from the technical teams.

Professional development

Common approaches to teachers' professional development start from mistaken assumptions that teachers' learning can be transformed by prescriptive approaches. The view of the team was based on a more complex view of professional learning (Fullan, 2007; Spillane, 1999) that saw the development of new spaces connected to new practices of organisation, management and use of the schools' Science spaces and to a Science Education reform that addressed improvements in pedagogy, curriculum and assessment (Osborne & Dillon, 2008). With this in mind, a country-wide professional development programme was designed to support teachers in practical aspects of the use of the Science Learning Studios, linked to the organisational and management aspects of the spaces, materials and equipment, and also the pedagogical ones, emphasising active learning methodologies making use of the new features of space. This professional development programme for teachers teaching in the intervened schools will be later described in more detail in chapter 6. In chapter 8, the design of a professional development programme on the organisation and management of Science Learning Studios will also be described, as one of the outputs of this work.

Lessons were also designed and taught in the new spaces to experiment in first-hand the elements of the Science Learning Studio in use. In these lessons the team explored several ideas to represent interactions with the features of the new spaces in teaching and learning activities, leading to a storyboard format of activity *recording*, useful in communicating the model in use to other teachers. This exploratory work later developed into a new concept that I call Pedagogical Graphic Novel, an essential piece to analyse activities in the Science Learning Studio, to be later presented in chapter 4.

Evaluation of the model in use

The Parque Escolar's programme had several evaluation studies, particularly those by Veloso & Sebastião (2011) and OECD/CELE (Almeida et al., 2009), mostly at a school scale. These did not provide a detailed analysis at a school Science' scale. This gap was one of the drives for this thesis, from which I departed to formulate some of the research questions.

2.6 Coda

In the analysis made by Gomes (2014) to the collections of Natural History in the "Liceus", from inventories dating from 1928, the mentions to the Science spaces for this subject are inconsistent, with terms such as "Laboratório de Ciências Biológicas e Geológicas", "Gabinete de Ciências naturais", "Laboratório de Biologia", "Material de Ciências Biológicas e Geológicas", "Gabinete de História Natural", "Gabinete de Mineralogia e Geologia", "Gabinete de Ciências", "Gabinete de Ciências-Naturais", "Gabinete de Biológicas", "Ciências Histórico-Naturais", "Gabinete de Biologia", "Gabinete de Mineralogia", "Instalações de Ciências, Geológicas e Biológicas", "Secções de Zoologia e Botânica e Mineralogia", "Museu e Gabinete de Ciências Naturais". This seems to be the case with most of the building plans across the XXth century for every subject, with rectors, architects, technicians and researchers naming schools' spaces in different ways (laboratories, cabinets, classrooms, etc.).

Across the XXth century, progressive and conservative views on learning and architecture alternated, in line with political or international influences, affecting construction plans and models of school Science spaces, from the early "Liceus" to the model "Liceus" of 1968 with more flexible spaces. As observed by Gomes (2014) and Brandão (Alegre, 2009), the role of the museum and amphitheatre lost ground to spaces that supported the active role of students, making available resources and furniture for individual and group work and for more expressive and diverse activities. However, the maintenance of regular classrooms for theoretical Science classes, without proper material and instruments, the decline of the lab technician career in the last century, and infrastructure problems of decaying buildings did not support the change from a rhetorical teaching in both regular classrooms and laboratories (adapted or originally designed), maintaining a centuries-old tradition of Science teaching close to the classical universities that still did not offer scientific courses, manifested in Laurentius de Voltolina painting:

Figure 2.50 – A representation of a University class by Laurentius de Voltolina, circa 1350 (Public domain)

The Science Learning Studio attempted to change space, but it would be naive to expect a significant change in teaching and learning activities. However, the concept of Studio, from its higher education to pre-school variants, does not distinguish itself by just its take in space and technology. Organization, curricula, pedagogy, assessment or professional development can be tightly integrated to improve student performance on traditional tests, cognitive tests and problem solving, students' attitude towards the subjects and courses, students' retention, attendance and success, teachers' attitudes towards the subject, teachers' professional culture and relation with the community. In the next chapter, I will review this concept to later synthesise its distinctive features, to establish a broader scope of the Science Learning Studio beyond space.

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3. From Studios to Science Learning Studios – A review

In chapter 3, I will engage some of the literature on learning Studios beginning by the Architecture Design Studios in higher education, the Reggio Emilia Atelier in early years' education and the Physics Studio at the undergraduate level, with a more detailed exploration of the SCALE-UP project in North Carolina State University and TEAL at MIT and how these multiple perspectives can work together to provide meaning to the concept of Science Learning Studio for secondary Science education.

3.1 The Design Studio

David Schon is one of the reference authors on reflective practice for the professional development of educators. One of his main arguments is that the schools of other professions have a great deal to learn from the Design Studio at the core of most architecture curricula, as it represents a throwback to an earlier mode of education and an earlier epistemology of practice. In the modern research University, where professional competence is seen as the application of systematic professional knowledge to the instrumental problems of practice, the accepted normative curriculum is constituted by the relevant basic Science, applied Science and a "practicum" in the workplace. However, the dilemmas of practice under conditions of complexity, uncertainty, uniqueness and value-conflict question this normative curriculum and give importance to indeterminate zones of practice, on artistry besides technical expertise and problem setting besides problem-solving (Schon, 1985, p. 5).

3.1.1 Learning in the Design Studio

In Schon's sense, the essential feature of Studio activities is that rather than requiring the application of knowledge to practical, well-defined problems, it requires of students an immersion in fuzzy, ill-structured projects, before knowing what to do or learn:

> It would pay attention to the strangeness of unique cases that escape the categories of established theories. And it would engage the appreciative, valued-laden questions as well as the technical ones. It would not eschew the use of research-based knowledge, but it would not assume that project tasks are only done, or best done, through the use of such knowledge. (Schon, 1985, p. 89)

What does a Design Studio look like and what activities do students engage in? Design Studios can accommodate 10 to 20 students, usually subsets of a larger Studio complex. Students can have desks assigned to them, with some storage space and bulletin boards, and collective areas for building scale models and larger drawings. During a Studio class, students can be required to fulfil a large design project and related, smaller projects, with the teacher providing some assignments in each class, 3 to 4 hours long. Shulman (2005) briefly characterises student' activity in these spaces:

> Quite a different classroom style is evident when one visits a design Studio that meets in the same building of the same engineering school. Here students assemble around work areas with physical models or virtual designs on computer screens; there is no obvious 'front' of the room. Students are experimenting and collaborating, building things and commenting on each other's work without the mediation of an instructor. The focal point of instruction is clearly the designed artifact. The instructor, whom an observer identifies only with some difficulty, circulates among the work areas and comments, critiques, challenges, or just observes. Instruction and critique are ubiquitous in this setting, and the formal instructor is not the only source for that pedagogy (p. 54).

Boling and Smith (2014) emphasise the presence of easily available and plentiful precedent representations of designs, flexible workspaces shared with other students, and available extended hours if not round the clock; public display of work and public discussion or critique as a primary mode of instruction; intensive practice in hands-on work; under-defined briefs (assignments with minimal definition) for projects; and intense relationships with fellow students, both more experienced and less experienced than each other (p. 39).

Figure 3.1 – Studios and public discussions in Yale University, USA (Yale School of Architecture, 2014)

3.1.2 Pedagogy of the Design Studio

As a signature pedagogy of the profession of architecture, the role of the instructor is to support and refine abductive reasoning in the design process, usually 1:1 by circulating between desks, inquiring and supporting students' reflection-in-action and reflection-on-action (desk crits), organising pin-ups (informal presentations to the Studio group) and reviews (formal presentations or reviews by a jury, with posters and models), ending the Studio class term with a public group exhibition (Georgia Tech College of Design, 2017). Several design thinking challenges are addressed through this teaching method:

> Design thinking incorporating abductive reasoning forces a designer to shift and transfer thoughts between the required purpose or function and the appropriate forms for an object to satisfy the purpose (Cross, 2011). In essence, designers move back and forth between an analysis space (required purpose or function) and a synthesis space (appropriate forms for an object to satisfy the purpose). The core challenge of design thinking is, in parallel, creating a complex object, service, or system and making it work (Dorst, 2011). Designers come up with the "what" and "how" and then test both in conjunction (Dorst, 2011, p. 5). Within a design space, designers need to tolerate uncertainty, interact with external representations (sketches, models, and other materials), rely on intuition, and take stock and reflect on the what and the how (Cross, 2011). (Tracey and Baaki, 2013, p. 1)

The idea of reflection-in-action is that ill-structured problems are understood through attempts to change them, and changed through attempts at understanding them (Schon, 1985, 1987). When absorbed in a reflective conversation with a design situation, reflection-in-action has three critical dimensions: 1) a designer's language as he describes and appreciates the particular consequences of design moves; 2) the implications that are discovered and followed, in an on-the-spot experiment; and 3) the changing stance toward a design situation (Schon, 1985).

Reflection-on-action refers to reflecting on something after it has happened through various methods, such as recording one's thoughts or talking about an event after it has taken place (Schon, 1985), engaging metacognitive skills.

A graphical way of representing reflection-in-action and reflection-on-action is that action (level 1) constitutes a subsumer (Ausubel, 2003) for a description of action, which provides content to reflection-in-action (level 3), and through elicitation, the description of the reflection-in-action (level 4) becomes a subsumer for reflection-on-action (level 5). This might go on, through elicitation and description of the reflection-on-action (level 6), etc.:

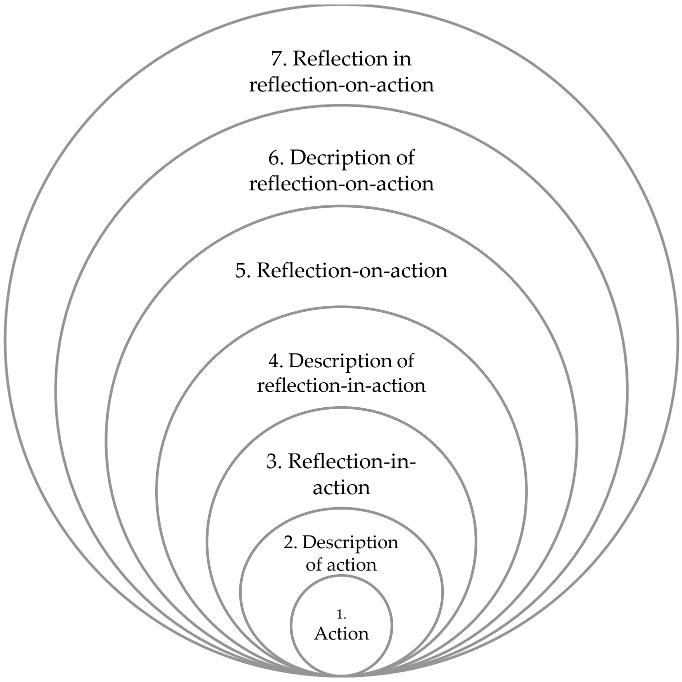


Figure 3.2 – Relationships and subsumers for reflection-in-action, reflection-on-action and reflection in reflection-on-action (adapted from Brockbank & McGill, 1998)

Concerning assessment in the Design Studio, De La Harpe and colleagues (2009) reviewed 118 journal articles in the last decade in art, architecture and design and the literature related to assessment, defending a model that at its core values the process, the final product and the person (growth), as all are considered crucial to good Studio learning, with impact on outcomes (p. 46).

The 11 categories for assessment proposed by the authors are grouped under three headings: outcome dimensions, knowledge & skills, and reflective & professional practice:

> Assessing outcome dimensions, or producing a 'good' outcome, focuses on the product, the process and the person – not simply on one or the other(s). Assessing knowledge & skills focuses on hard skills (such as creativity, innovation, problem solving, critical thinking), soft skills (such as communication, collaboration, social and ecological awareness), and content knowledge; as well as technology use and learning approach/style. Assessing reflective & professional practice, or thinking like an artist or designer, encompasses professional and innovative practice, reflective practice skills and interdisciplinary collaboration. (De La Harpe et al., 2009, p. 47)

Table 3.1 – Indicators, definitions and example statements for assessment in the Studio

Indicators	**Definitions**	**Example statements**
Product	Outcome of process, emphasis primarily on product (event or object)	Design product, end product, design results, artwork, technical solutions, project representations, responses to works of art

Indicators	Definitions	Example statements
Process	Process involved in developing outcomes rather than emphasis on product	Development of design ideas, working through the artistic process, exploring the idea and the design process
Person	Student/ human/ emotional aspects	Educational process from student's perspective, care in the context of classroom practice, including thoughts and feelings when displaying work for critical response
Content knowledge	Underpinning body of knowledge of discipline	Design fundamentals, design knowledge, knowledge of aesthetics, programme content basics such as history, theory, contemporary practice
Hard skills	Art/design thinking and competence, cognitive and technical skills in the art/design process	Skills of integration, projection, exploration, innovation, critical thinking, problem framing/solving, decision making – basics of design thinking, sketching, painting or drawing techniques
Soft skills	Non-technical and people skills	Teamwork, communication, verbal and visual literacy skills, making of personal meanings, developing positive attitudes, confidence, cultural and ecologically sensitive awareness
Technology	Use of hardware, software, information communication technologies, mobile devices, virtual Studio	Application of new technologies and materials, using high end computer graphics and low and high bandwidth internet technology, using technology to communicate online
Learning approach/style	Learning strategies and methods, ways of learning	Exploring methods of learning and effectiveness for design knowledge building, helping students learn from others, expanding conceptions through dialogue journals or visual
Reflective practice	Reflective thinking, reflection in and on action	Becoming more rhetorically astute, systematically reflecting on habitual thinking and actions, evaluating and adapting to the ambiguous, knowledge-building nature of the practice
Professional & innovative practice	Industry and professional capability, new ways of working, transforming praxis	Responding to challenges in the business environment, staying current, being sensitive to pressures of real world practice, preparing for demands of professional life/work
Interdisciplinary collaboration	Working/collaborating with others in different disciplines/subject domains	Experiencing inter/multidisciplinary and cross-curricula projects, working as part of a development team comprising people from different professional backgrounds

3.2 The Reggio Emilia Atelier

The Reggio Emilia preschool educational philosophy began in post-war Italy, in the municipality of Reggio Emilia, led by Loris Malaguzzi. In a local context where preschool education was dominated by the church, where the PCI ("Partido Comunista Italiano", Italian Communist Party) had a stronghold and the culture of participation of society in public affairs was strong, parents led efforts to open schools for young children. These efforts eventually led, after 30 years, to a full movement extending beyond Italian borders, keeping the name of the original city, Reggio Emilia. This approach to preschool education, that is, for both children younger than 3 or between 3-6 years old, has as one of its innovations the Atelier, a space that besides the plaza and the regular classrooms, intends to develop the hundred languages of children, through expressive learning using multiple materials, the body, project work and negotiated learning.

The typology of spaces of a Reggio Emilia school includes:

1. The entrance hall, which informs visitors and documents activities in the school, with access to the dining hall, with a visible kitchen;
2. The piazza, the place of encounters, friendships, games and other activities beyond the classrooms, connected to it;
3. Classrooms are divided into two contiguous rooms, one for collective work, the other for children to stay alone if they need to. Next to each classroom, there is also a mini-atelier, allowing for extended project work. There are also rooms for music and archives for storage;
4. The Atelier, one of the landmarks of this kind of school, is a kind of Studio and laboratory, a place for manipulating and experimenting with visual languages, sometimes combined with verbal ones.

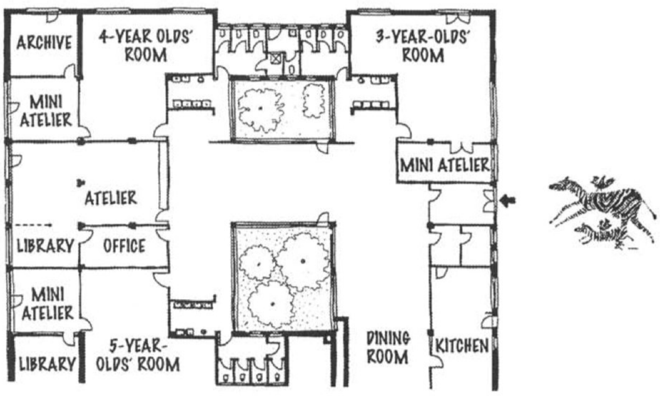


Figure 3.3 – Diana school map (Edwards et al., 2004, p. 171)

Throughout the school, the walls are decorated with both temporary and permanent exhibits of what children and teachers have created. They speak and document. Glass walls separate working spaces to support a communal feeling (Edwards et al., 2004, p. 64).

In the words of Malaguzzi, much hope was put into the introduction of the Atelier in these schools. If possible, a new school typology would be made entirely of this kind of spaces, where the hands of children could be active for "messing about" (Edwards et al., 2004, p. 73).

Figure 3.4 – The atelier and "atelierista" in the "scuola communale dell'infanzia" Diana (Vecchi, 2010, p. 3 and p. 41)

Furniture in the Atelier includes children sized tables and chairs, either individual or for groups, light and mirror tables, paper racks, wall shelving units, display units, movable display racks, carts, storage units, platforms with box-like elements to create floors at different heights, *landscapes* to climb, explore, and experiment with, for playing in groups, roleplaying or sleeping.

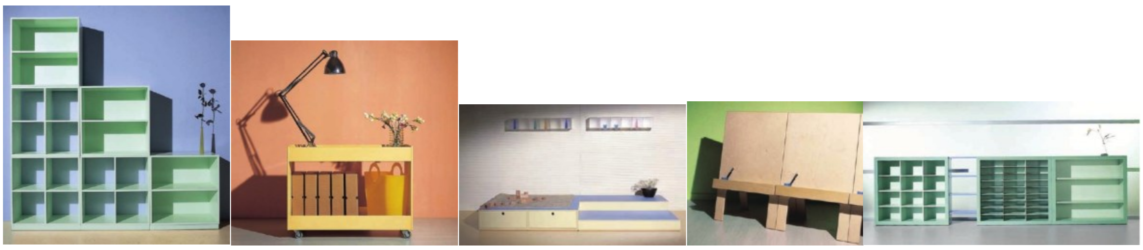


Figure 3.5 – Several furnishings available in Reggio Emilia classrooms and Ateliers (Atelier3, 2002)

The materials and tools available are very diverse, supporting multiple visual arts techniques. These can be stored in transparent boxes and trays, with easy access from children.

Figure 3.6 – Atelier in “La casa amarilla”, Peru (La casa amarilla, 2017)

3.2.1 Learning in the Atelier

One of the distinctive features of the Reggio Emilia approach is the involvement of children in extended in-depth investigations, an influence of the progressive movement by Dewey and others in the beginning of the XXth century and later applied in countries such as the UK as open education. Activities of this kind can be:

> (…) on a topic such as "What happens at the supermarket?" or "How houses are built," children explore the phenomena first-hand and in detail over an extended period of time. The activities of the children include direct observation, asking questions of relevant participants and experts, collecting pertinent artifacts, and representing observations, ideas, memories, feelings, imaginings, and new understandings in a wide variety of ways including dramatic play. Most pre-schoolers — at least at age 3 or 4 — are not yet easily able to represent their observations, thoughts, and new knowledge in writing. They may, of course, dictate their thoughts and observations to others who can write for them. The first major lesson from Reggio Emilia is the way their young children are encouraged to use what they call graphic languages (Rinaldi, 1991) and other media to record and represent their memories, ideas, predictions, hypotheses, observations, feelings, and so forth in their projects. Observations of the children at work in Reggio Emilia reveal how a wide variety of visual media are used to explore understandings, to reconstruct previous ones, to construct and to co-construct revisited understandings of the phenomena investigated (Edwards et al., 2004, p. 28).

Visual and graphic languages are a way of children to express and communicate when the domain of verbal and written language is still limited. In this sense, the visual arts are additional languages available to them, and are not taught as a subject for its own sake (Edwards et al., 2004, p. 35)

Besides project based learning, spontaneous play with blocks, dramatic play, outdoor play, listening to stories, cooking, housekeeping, dress-up activities, painting, collages and clay work are available to children daily. The role of the child as researcher takes place within the context of projects, exploring, observing, questioning, discussing, hypothesizing, representing, and then revisiting their initial observations and hypotheses to further refine and clarify their understandings, thereby expanding the richness of their thinking, and further defining their role as that of a researcher (Hewett, 2001, p. 96).

The romantic view of the child, reminiscent of Froebel, considers that she has rights beyond needs, and her nature, thoughts, and work are taken seriously, listened to, and respected. The child is viewed not as a formal student but as an apprentice, the lead author of its own learning, working with others in the discovery and construction of solutions to meaningful questions and problems; learning is not something that is done to the child, but rather something she does (Hewett, 2001, p. 96).

Collaboration, dialogue, conflict, negotiation, and cooperation with peers and adults support the belief that only as children articulate to others that which they believe to be true do they come face-to-face with errors in their thinking (Hewett, 2001, p. 96).

3.2.2 Pedagogy in the Atelier

The teacher-child relationship is focused on the activity itself, rather than just the routines or the child's performance on academic tasks:

> Adults' and children's minds meet on matters of interest to both of them. Both the children and the teachers seem to be equally involved in the progress of the work, the ideas being explored, the techniques and materials to be used, and the progress of the projects themselves. The children's roles in the relationships were more as apprentices than as the targets of instruction (Edwards et al., 2004, p. 36)

The teacher is a collaborator and co-learner, demonstrating respect for the child's rights by mutual participation and joint action and in collaborative efforts with colleagues and parents. The teaching activity centres on provoking occasions of discovery by being alert, facilitating and stimulating children's dialogue, co-action, and co-construction of knowledge, providing the tools necessary to achieve her personal goals and advance her mental functioning (Hewett, 2001, p. 97).

The role of research and reflective practice is key in this teaching activity, manifested through extensive documentation of the learning process. The compilation of large amounts of data such as photographs of the children engaged in activities, artwork in various stages of completion, videos, transcribed audio recordings of children's conversations with peers and adults, supports discussion and reflection in routine meetings with colleagues, conversations with parents, experts within the community and the children themselves. Some of the data is displayed in panels in walls in the school or in small books, slides or videos.

The documentation process has many applications: 1) it contributes to the extensiveness and depth of learning from children's projects, individually and stimulated by each other's work; 2) communicates to parents the children's activities in school, providing a rich basis for both an inquisitive approach from their part and the sharing by children of their school experience; 3) sharpens and focus teachers' attention on the progress, intentions and understandings of the children and their role in children's activities, providing a snapshot of practice that informs the modification and adjustment of teaching strategies, a source of ideas, and an impetus for the creation of new ones; 4) provides a snapshot of practice to guide discussion among teachers (Edwards et al., 2004, p. 39).

Co-teaching supports the break from the traditional professional and cultural isolation of teachers. Teachers work in co-teaching pairs in each classroom, and the activities' planning process is made with colleagues and families. All staff members meet once a week to discuss cases and share ideas and participate together in in-service training. A team of "pedagogisti" (pedagogical specialists) facilitates interpersonal connection and considers both the overall ideas and the details.

Community-based management, communal life and community presence are also distinctive features of this school model. Malaguzzi describes what this means in practice:

> Once a week we would transport the school to town. Literally, we would pack ourselves, the children, and our tools into a truck and we would teach school and show exhibits in the open air, in the square, in public parks, or under the colonnade of the municipal theater. The children were happy. The people saw; they were surprised, and they asked questions. (Edwards et al., 2004, p. 52)

Participation of parents in their children school life is encouraged in several ways, such as meetings at the individual classroom level, small group meetings, individual parent-teacher conferences, meetings around a theme, encounters with an expert, work sessions and labs, holidays and celebrations and other activities such as trips to town, picnics, excursions, short holidays, day at the school, among others (Edwards et al., 2004, pp. 105-106).

More formal aspects of community-based management take place in institutional bodies with responsibilities in running the schools. Every 2 years the parents, educators, and citizens elect representatives to the Advisory Council for each infant-toddler centre and pre-primary school. Two or three representatives from each Advisory Council are elected to sit on the Municipal Board on Infant-Toddler and Pre-primary Education, together with the Administrative Director of Early Education, the team of "pedagogisti", the elected city official in charge of education, and the Mayor.

> In recent years, 75% of the parents have voted in the elections for the Advisory Councils. And many have served. For example, in 1993-1996, out of 2,550 families using our municipal early childhood services, 554 parents were elected; that means that one out of five families participated in the running of the infant-toddler centers and preprimary schools. (Edwards et al., 2004, p. 106)

Children also assume responsibility for some of the daily activities of the school, such as setting the tables for meals, tidying up afterwards, working with the cooking staff, and sharing responsibility for keeping the art materials in good order (Edwards et al., 2004, p. 41).

"Pedagogisti" work within a team in the political and administrative branches of city government, contributing to their executive, managerial functions. Besides that, they are also responsible for the ongoing professional development and in-service training of teachers and staff. Each "pedagogista" is responsible for a certain number of infant-toddler centres and pre-primary schools, and each also has other specific responsibilities within the system (responsible for the centre of documentation and research, keeping track of ICT innovations, building environments, etc.). (Edwards, 2004, p. 129)

3.3 The Physics Studio

In the 1980s there was a growing interest in the Physics Education Community in the USA on the application of technology to Physics education, such as the creation of microcomputer-based laboratories, digital video, simulations, modelling and numerical approaches to problem-solving. Redish and Wilson formed the CUPLE consortium, an acronym for the Comprehensive Unified Physics Learning Environment integrating some of these innovations in Physics education into a common user interface, file structures and common mechanisms for data exchange. Several modules developed in this project were deployed in the traditional Physics course at Rensselaer Polytechnic Institute as laboratory modules, homework, or in class activities. Influenced by Priscilla Laws' Workshop Physics approach and research on cooperative learning and limited by its applicability to a large research University with 1000 students in Calculus and 600 students in Physics each semester, they developed the Studio classroom concept for these subjects, borrowing it from the architecture and artists' Studios (Wilson, n.d.).

This canon of the large lecture, small recitations for problem solving in small groups and the separate laboratory was still the dominant organisation of students' activity in large universities, with faculty responsible for lecturing and teaching assistants supporting recitations and laboratory work. The goal of the Studio courses was to bring the interactivity often found in small enrolment interactive courses into the large enrolment courses, through a combination of lecturing, recitation and laboratory work into integrated sessions hosted in the Studio space. A team comprised of faculty, teaching assistants and in some cases, undergraduate students, taught the classes (Wilson, n.d.).

What is argued by Beichner and others (2007) regarding the Physics Studios is that the "most effective instruction is where all components of the course work tightly together towards the same goal" (p. 3). In North Carolina State University (NCSU) this Studio concept in part of the SCALE-UP initiative (Student-Centered Activities for Large Enrollment Undergraduate Programs). In the Massachusetts Institute of Technology (MIT), it is called TEAL, Technology-enabled Active Learning. In September 2007, with the support of UIED and the hospitality of both the projects' mentors, Robert Beichner and John Belcher, I had the opportunity, together with my colleagues Clara Boavida e Sandra Martins, to visit both these Studios and experience two Physics classes for undergraduates.

3.3.1 SCALE-UP

The SCALE-UP project started in the Physics Education Department of North Carolina State University, following an integrated Mathematics, Physics, Engineering, and Chemistry project (IMPEC, from 1993-1997). This previous project, where the Studio concept was already being used, mainly focused on small class settings (affecting 36 students a year), raising the challenge to adapt it to larger enrolment courses as it was impractical to use this approach with thousands of students, due to the available resources. The focus on social interaction and hands-on, minds-on activities are distinctive aspects of this approach. The SCALE-UP main goal "is to develop techniques and materials that permit use of research-based pedagogies in large-enrolment Studio classes of up to 100 students" (Beichner et al., 2007, p. 4).

Since its inception, this concept suffered several iterations, combining aspects of curriculum, pedagogy, assessment, technology and spaces design. Today, the model has sparked worldwide adoption, with literature mostly themed on quasi-experimental studies or innovation adoption.

Figure 3.7 - Two SCALE-UP "improvised groups", with Robert Beichner standing, in the right. On the left, siting and standing, two teaching assistants, and the Portuguese visitors, sitting from right to left: Sandra Martins, João Fernandes and Clara Boavida

Being in a particular lesson taking place in the Studio in NCSU is quite different from being in a large lecture hall. The more relaxed and collaborative tone of the classroom can encourage dialogue and experimentation. The physical space supports this also, allowing easy circulation between the round tables and providing access to tools.

Figure 3.8 – Final minutes of a SCALE-UP lesson

The space organisation is quite different from either a lecture hall or a Physics lab. Imagine a banquet hall and you will have a closer image of this kind of setting.

Figure 3.9 - Teacher’ control station in a SCALE-UP Studio

The teacher has a small station, from where he manages part of the lesson. One of his main tasks is to circulate around the tables and dialogue with the students. One teaching assistant helps in this task, being enough to support more than 100 students.

Figure 3.10 - Projector, projector screen, camera and speakers

Concerning the activities, brief periods of lecture, often less than 10 minutes, are intertwined with tangibles and ponderables, types of activities will be later explained. Sometimes, more open-ended practical work and problem solving and quizzes using an online management system take place.

The weekly classes can be of 4 to 6 hours, usually in 2 hours blocks with 50 minutes followed by a 10 minutes’ break and a 60 minutes’ period.

Asking some students what they feel about this kind of classes, one common answer was:

> I like it. It's a lot better than regular lectures, we get to try things and it's not just talking. (personal communication of one student in the Studio)

Some other students' comments (Beichner & Saul, 2003, p. 65) are:

> I can deal with the lecture class, it's just that I enjoy more...getting more into the interactive projects. It's more hands on. If you don't understand something, you just ask the guy next to you. Nobody yells at you for talking (…)
>
> You have a professor right in the middle and... a couple of guys spread out and you can flag them down...In the lecture, you are sitting... 25 rows back. You really don't have anyone but the two people next to you and they don't know. You really don't have anyone with some knowledge to help you out.

Curriculum

Improving learning is not just a matter of spaces. Every aspect of the course should support the underlying vision, and the curriculum is a key part.

The goals devised for the curriculum of Physics for undergraduates in NCSU are as follows (Beichner et al., 2006, p.3):

I. Students should develop a good functional understanding of Physics. They should be able to:

1. Describe and explain physics concepts, including knowing where and when they apply;
2. Apply Physics concepts when solving problems and examining physical phenomena;
3. Apply concepts in new contexts (transfer);
4. Translate between multiple representations of the same concept, for example: between words, equations, graphs, and diagrams;
5. Combine concepts when analysing a situation;
6. Evaluate explanations of physical phenomena.

II. Students should begin developing expert-like problem-solving skills. They should be able to:

1. Satisfactorily solve standard textbook exercises;
2. Apply all or part(s) of the G.O.A.L. [Gather information, Organise your approach, Analyse your approach, Learn from your efforts] expert problem-solving protocol in any context;
3. Solve more challenging problems, including:
   - Context-rich ("Real World") problems;
   - Estimation problems;
   - Multi-step problems;
   - Multi-concept problems;

- Problems requiring qualitative reasoning;

4. Evaluate other people's written solutions and solution plans.

III. Students should develop laboratory skills. They should be able to:

1. Interact with (set up, calibrate, set zero, determine uncertainty, etc.) apparatus and make measurements;
2. Explain the underlying physical principles of the operation of the apparatus, measurements, physical situation being studied and analysis of data;
3. Design, execute, analyse, and explain a scientific experiment to test a hypothesis;
4. Evaluate someone else's experimental design.

IV. Students should develop technology skills. They should be able to:

1. Use simulations to develop mathematical models of physical situations;
2. Utilise a spreadsheet to graph and do curve fitting;
3. Find information on the web;
4. Use microcomputer, video, and web-based software and hardware for data collection and analysis.

V. Students should improve their communication, interpersonal, and questioning skills. They should be able to:

1. Express understanding in written and oral forms by explaining their reasoning to peers;
2. Demonstrate their knowledge and understanding of Physics in written assignments;
3. Discuss experimental observations and findings;
4. Present a well-reasoned argument supported by observations and physical evidence;
5. Evaluate oral arguments, both their own and those espoused by others;
6. Function well in a group;
7. Evaluate the functioning of their group.

VI. Students should develop attitudes that are favourable for learning Physics. They should:

1. Recognise that understanding Physics means seeing the underlying concepts and principles instead of focusing on knowing and using equations;
2. See Physics as a coherent framework of ideas that can be used to understand many different physical situations;
3. See what they are learning in the classroom as useful and strongly connected to the real world;
4. Be cognizant of the scientific process/approach and how to apply it;
5. Indicate a willingness to continue learning about Physics and its applications;

6. See themselves as part of a classroom community of learners.

Pedagogy

> The big picture is the same (...) you just give a student something interesting to explore and that frees the instructor out to walk around and talk to them and get them to talk to each other. (Robert Beichner, personal communication, September 19, 2007)

The underlying pedagogy of the SCALE-UP approach intends to (Beichner et al., 2007):

> 1. Create a cooperative learning environment that encourages students to collaborate with their peers, questioning and teaching one another;
> 2. Use PER-based activities as much as possible and to minimize lecture during class;
> 3. Coach the students during activities by assisting them in answering their own questions and by letting students present their results to the class for review by instructors and peers as opposed to just telling students the answer. (p. 5)

Students typically begin a topic by doing assigned readings before class. In these assigned readings, they are required to express the key ideas of the subject in their own words, followed by an assignment based on the reading. These key ideas and concepts are approached during the in-class activities, and other skills such as multiple visual representations are also addressed, being applied in experiments and problems. Finally, they also are assigned homework to practice what has been learned and to develop a richer understanding of the theme (Beichner et al., 2007).

Tangibles and ponderables

> Do they do that? Oh sure, they do lots of stuff. (Robert Beichner, personal communication, September 19, 2007)

SCALE-UP classes involve a lot of *doing* and thinking about the *doing*. For a start, students are presented with an outline of each day's class usually on a single web page (equivalent to one screen area), working as an advance organiser of the day's work.

The activities in the Studio are called *tangibles* and *ponderables*, consisting of hands-on activities and simulations in the first case and interesting questions and problems related to complex real-life situations in the second. Besides this, there are also some hypothesis-driven laboratory assignments where students must write detailed reports like in any practical class.

> They are very busy. In this class it's typically more work than other classes. We check their notes, their in-class notes, and their out-of-class notes and grade them on those. We found that if we don't then they don't take very good notes. And we think that is important. It is graded in a check +, check, check -. (...) We actually do that

during class. One of the TAs goes around and does the checking. (Robert Beichner, personal communication, September 19, 2007)

Tangible activities are usually short tasks related to physical situations, where students must gather data, and make hands-on measurements or observations. Examples go from determining the thickness of a single sheet of paper in their textbook, calculating the number of excess electrons on a piece of transparent tape after it is pulled up from the table top or calculating the desired spacing of frets on a guitar (Beichner & Saul, 2003, p. 62).

> For example, groups are given a piece of paper with a pair of concentric quarter-circle arcs. Their task is to roll a racquetball through a curved path between the arcs. Students sometimes tip the paper or spin or blow on the ball to accomplish the task. They are asked why they need to do this (and references are made to Newton's Second Law.) Once they state that they are applying a force to the ball to change the direction of its motion, they are asked to specify the direction of the force. Socratic dialoguing eventually results in the recognition that the force is always directed toward the centre of the concentric arcs. They quickly recognize this as a centripetal force and then have to approximate its magnitude from the mass of the ball and an estimate of its speed. (Beichner et al., 2007, p. 13)

In the case of ponderables, these similarly require estimating or finding values from the web, but no observations are required. Students are asked questions like "Estimate the number of steps it takes to walk across the country" or "How far does a bowling ball skid before its motion is purely rolling?". Students are encouraged to make estimates of information they cannot conveniently measure, seeming to recall *Fermi Questions*, or the sometimes called *Back of the Envelope Calculations* (Beichner & Saul, 2003).

Building on the work of Eric Mazur on Concept Tests and Peer-Instruction (who I also had the opportunity to visit in Harvard), some questions are presented in WebAssign, an online platform for the course resources and activities, using short, multiple-choice questions to identify students' difficulties in a practical way. The pedagogy was also guided by qualitative elicit-confront-resolve ponderable activities to address student conceptual understanding. But there are also problems that require numerical answers so that students can see others' results and challenge their approaches (Beichner et al., 2007).

The main question in all the activities in class is "Why are we doing this?" or "What am I supposed to learn from this?" These questions are addressed generally at the end of a task, asking students to write in their notes or in their neighbours' the answers. This is a way of verbalising the meaning they take from the activities and its goals:

> I mean, we make sure we don't give them busy work. Busy work is a phrase given to work that you do just to do the work. There's no real value to it. And so with every assignment they are supposed to think about "what am I supposed to learn from this" in fact, we'll ask them to write that down some times. (Robert Beichner, personal communication, September 19, 2007)

Lab work and problem-solving

Besides the short tangible and ponderable activities, there is more extensive, group-based laboratory work that requires a formal report to be delivered in the end, just like any practical class. The equipment for these experiments is kept close so that students can reach them easily. One of the main goals of this kind of work is to develop practical skills.

It has also been adapted to SCALE-UP a problem-solving activity called Real World Problem Solving based on the Cooperative Group Problem Solving (CGPS) approach developed by the Physics Education Group at the University of Minnesota. The advantages proposed for this method are, according to its authors (Physics Education Group, n.d.):

1. The structured problem-solving strategy seems too long and complex to most students. Cooperative-group problem solving gives students a chance to practice the strategy until it becomes more natural;
2. Groups can solve more complex problems than individuals, so students see the advantage of a logical problem-solving strategy early in the course;
3. Each individual can practice the planning and monitoring skills they need to become good individual problem solvers;
4. Students get practice developing and using the language of Physics - "talking Physics";
5. In their discussion with each other, students must deal with and resolve their misconceptions;
6. In subsequent, whole-class discussions of the problems, students are less intimidated because they are not answering as an individual, but as a group.

Modelling and Simulation

Some assignments use an open source software called Visual Python (VPython) where students create simulations. The simulations are done more in Mechanics that in Electricity and Electromagnetism:

> They look at the objects as the thing that they have to teach as Physics students. (Robert Beichner, personal communication, September 19, 2007)

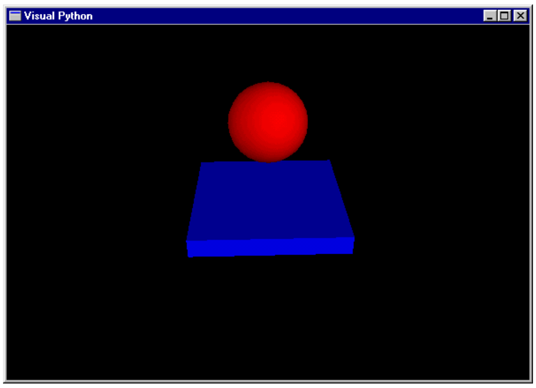


Figure 3.11 - A visual representation of objects with physical behaviour (Hidayat, 2007)

Cooperative learning

Most assignments in a SCALE-UP class are collaborative, in groups of 3 students of 3 different attainments levels: top, middle and bottom. The selection is based on pre-test scores or grades in previous coursework, if the year is starting, or in their results during the semester. The selection also tries to maintain an average ability between all groups.

The best students can act as supporters for the rest of the group, with one in each table. The middle and bottom students are then randomly assigned to groups, evenly distributed into the tables. About this separation according to attainment level, and the top students helping the rest of the group, Robert Beichner states:

> We have to motivate them to do that. Because usually the stronger students don't want to work in a group because everybody slows them down. So what we do is we tell them to study together with your group. If your group average is 80% or better, then everyone in the group gets 5 more points. So, if you are the top person in the group you are probably motivated by points because top students often are. It's to your benefit to make sure everyone understands the material. And of course, you will learn it even better like that. (personal communication, September 19, 2007)

About the bottom students, he also refers:

> The weaker students don't want to work in groups just because they are lazy and don't want to work. (…) If I am the weak person in the group and I don't do my job, then the people of the group can fire me. What that means is that I will have to do all the group assignments all by myself and that is 3 times the work! So, we only had one person fired in ten years of doing this, because they are trying to avoid that. (id.)

Another criterion considered in the group distribution is that of inclusion. Students commonly underrepresented, such as females or other minorities in engineering are not alone in a group. In this way, a female is always with another female in a group. This process pretends to improve the influence of women and minorities in the group, generally not the case when they are alone.

The groups are switched three or four times per semester, usually after each exam. This is done to encourage a productivity climate, as the groups can become so comfortable with each other that their in-class discussion topics start to be more about basketball games and parties than Physics.

About successful collaboration, five required characteristics of successful group-based instruction are:

- Individual accountability;
- Positive interdependence;
- Opportunities for interaction;
- Appropriate use of interpersonal skills;
- Regular self-assessment of group functioning.

Not incorporating all these aspects is a recipe for failure, at least as far as group functioning is concerned (Beichner & Saul, 2003, p. 62).

To reinforce the skills necessary to these successful interactions, early in the semester, students receive a brief training in group functioning and write and sign contracts of responsibility, a process that is repeated every time a new group is put together. The contract involves a clause for firing elements of the group that do not collaborate effectively. It is interesting that despite the fact of class attendance not being a requirement, peer pressure is effective in keeping the average attendance rates above 90 %.

Assessment

Typically, in the Physics Studio, the course assessment involves 4 tests, a final exam, one quiz every week, lab work and report writing, homework, individual class notes checking and data on each ponderable and tangible activities. Homework counts more than usual (20 – 25 %), encouraging students to do it. Contrasting with this, mid-term exams are weighted lower than usual (10 – 15 % each) allowing students to recover if they have a bad result in an individual test.

Online reading quiz assignments required before the class encourage students to be well prepared:

> We give them a quiz every week and the purpose of the quiz is to give them some feedback so that they know whether they do understand the material or not. Because part of the problem when you are working so much with other people, you think their understanding is yours. (Robert Beichner, personal communication, September 19, 2007)

In the weekly quiz, the first submission is done by each student individually. If they get a bad grade, they can repeat it with the help of the rest of the group, earning in this case only 75 % of the grade of this second quiz.

Grades are not curved (norm-based grading) but are rather based on the achievement of specific objectives (criterion-based grading). This encourages student collaboration has it eliminates the hierarchy of grades.

After any ponderable or tangible, there is a very short in-class assignment using a Learning Management System, with different types of questions to keep motivation high. The automatic answer checking in these quizzes is turned off, giving space to discussions about the strategies used to solve the exercises, and they are password protected (which is given by the teacher in class) to avoid students to solve it before class.

To improve self-awareness, everyone examines its own performance in teamwork and every element's roles (manager, recorder, or sceptic). These self-assessments are worth 10 % of the grade. Peer-assessment is often used when collaborating in A3 sized whiteboards available to each group.

Technology and materials

The main ICT technologies used in a SCALE-UP class are:

1. Networked laptops, with software such as spreadsheets and modelling (VPython) for each group of 3 students. Laptops help to keep sightlines and allow the class to put the lids down when necessary;
2. Internet, with online software such as WebAssign, a web-based problem delivery and grading system developed in the department of Physics Education at NCSU. This helps to gather assessment information, reduce the amount of hand grading, distribute information, allow communication, in-class polling and peer-assessment with less effort. Access to the syllabus, a calendar, daily activities, and examples of notes and lab reports is also done;
3. Two projectors and 2 projection screens as there is no room front;
4. Data loggers and related software, to allow real data gathering and measurements;
5. One digital visualizer for the teacher, allowing him to show objects, students work, transparencies or textbooks;
6. Wireless microphone and audio system for the teacher to allow recording and increase audibility;
7. A tablet PC for the teacher, allowing easy drawing and pre-prepared whiteboard *workspaces*;

8. Cameras for security reasons and to record classes and show students' work if needed.

Technology is used in several ways, from data collection, analysis (using Microsoft Excel), mathematical modelling (using VPython and Interactive Physics, a simulation software, to a lesser extent), microcomputer-based laboratories, video-based laboratories with video analysis (using Video-Point, a video analysis software), applets, mostly Physlets (Christian & Belloni, 2013) and simulations.

During the class, an important part of the lecture moments was supported with the tablet PC and the software Microsoft OneNote, in drawing, creating schemes and manipulating information. One student was asked to work on the tablet in front of all the class.

Materials for lab work and tangibles are brought from outside the Studio. In the case of TEAL, described in the next section, there is a prep room next to the Studio where materials are stored for easy access.

Spaces

The Studio concept proposed, concerning the spaces design and equipment (Beichner et al., 2007):

1. Eliminates the room front;
2. Provides round tables for 3 groups of 3 students each, with a diameter of 2 meters to allow space for experimental work apparatus along with note taking and laptop use. This setting also promotes group work and encourages inter-group communication;
3. Provides office-like chairs with wheels to facilitate rearrangements;
4. Has a spatial configuration that allows teachers to freely circulate between tables;
5. Provides extended whiteboard areas that support group discussions, either in walls or handheld. These increase the drawing area and constitute public thinking spaces that can be shared and discussed by the group or the entire class;
6. Identifies each student with a by table color-coded name tag to avoid anonymity;
7. Facilitates access to lab equipment.

The tables are used as an organisational system, being numbered and with each group in a table being assigned a letter, A, B or C. This identification system facilitates management, for example, to easily select one table to deliver homework, present their work, or be assigned part of a task. Another example of use is asking all the A groups in the room to work on specific tasks, in a jigsaw type of activity.

Impact

The findings of comparison studies between SCALE-UP and Lecture/Laboratory classes are summarised below (Beichner et al., 2007, p. 37):

- Conceptual understanding is increased;
- The top third of the class show the greatest improvement in conceptual understanding;
- Ability to solve problems is as good or better;
- Attitudes are improved;
- Class attendance is higher, typically > 90 %;
- Failure rates are drastically reduced (typically 50 %), especially for women and minorities;
- Performance in the second-semester Physics class is improved, whether taught traditionally or in SCALE-UP;
- Failure of at-risk students in a later Engineering Statics class is cut in half.

3.3.2 TEAL

The TEAL project expanded on the work of SCALE-UP and others by adding a large component centred on active and passive visualisations of electromagnetic phenomena (Beichner et al., 2007).

Figure 3.12 - A TEAL Studio round table with computers for groups of students

The TEAL project began with two prototype courses (about 170 students each) in Electromagnetism in Fall 2001 and Fall 2002 and moved to the large mainline course (550 students) in electromagnetism in Spring 2003. A similar effort in Mechanics was taught in prototype form in Fall 2003 and Fall 2004, and in the large mainline course in Fall 2005 (Beichner et al., 2006).

The cost of one Studio project, in the words of its mentor, John Belcher, was around $1-1.5 million (personal communication, September 21, 2007). The cost, superior to the SCALE-UP Studio in North Carolina had to do mainly with two things:

- The cost of building the visualizations and other curriculum materials, mainly presentations, to minimize the load of faculty;
- The room, the higher number of projectors and whiteboards, the computers and a touch-screen control console for the teacher. (Belcher, personal communication, September 21, 2007)

Figure 3.13 - Several projectors and projection screens, and a column with whiteboards in a TEAL Studio

The room has multiple projections in every wall, controlled from a console in the teacher's control module.

Figure 3.14 - The touch-screen console in the teacher's control module in a TEAL Studio

The touch-screen control console allows the teacher to interleave different projections according to the positions of the projectors. For example, in half of the projection can be shown a direct camera input from an experiment and in the other half a visualisation of the underlying phenomena.

Figure 3.15 - The prep room next to a TEAL Studio

There is a prep room adjacent to the main TEAL classroom. When preparing a lesson, a teacher can have the support of a lab technician, which can provide help in the selection of the apparatus and with any problem during the class concerning the technology.

The main reasons to change to TEAL had to do with increasing students' engagement with the course by using teaching methods that are more interactive and with proved results in other institutions, reintroducing a laboratory component into the mainline Physics courses after a 30 years' absence (Beichner et al., 2007).

Visualisations

The visualisations are one of the distinguishing marks of TEAL. Mainly in Electricity and Magnetism, there are a set of videos and java applets concerning Faraday's Law, magnetic inductance, among many other phenomena. These resources are available freely, with many others, through the MIT OpenCourseWare website (OCW), and can be used by any Physics teacher. They have received national and international prizes.

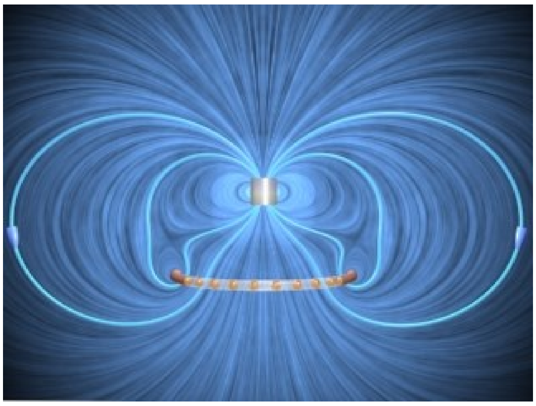


Figure 3.16 - An example of a visualisation used in a TEAL Studio. (OCW, 2005)

Typically, before doing an experiment, students are given a formal lecture about the theoretical aspects of the experiment. After a brief on the experiment, they are required to make some predictions about what they should see in the various phases of the experiment, based on the previous lecture. The predictions are made in the same way than the already mentioned Concept Tests, using a polling device that displays their answers anonymously in graphical format in the projection boards. The teacher continues to the experiment only after the students have correctly predicted the outcome of the various phases of the experiment (Beichner et al., 2007).

After the experiment, the measurements are compared to the predictions made. A new voting exercise is made, interleaved with a lecture by the teacher to give some feedback on the main difficulties of the class. In this follow-up process, the teacher uses visualisations that display aspects of physical phenomena which are invisible to the naked eye. TEAL visualisations use Java 3D applets, Macromedia Shockwave, and animations produced with 3D Studio Max (a modelling and animation software).

Students and teachers' motivation in the TEAL Studio

The motivation of teachers and students was one of the aspects that surprised John Belcher in the TEAL project. In his words (personal communication, September 21, 2007), concerning teachers:

> The rewards in a research university like MIT are predominantly rewards for research. Certainly, people are very interested in teaching but nonetheless, a lot of it is altruistic, that is you do it because you think that is the right thing to do.

Also, the workload for the teacher in the first year of adaptation can be high:

> It's more work. [for the teacher] Lecture is the easiest thing to do. I guess when I was lecturing nobody asked me a question. I could have gotten up and say: the moon is made of cream cheese. There's no interaction and no challenge. While in here, you have to interact and think what they are thinking.

Concerning students, curiously TEAL:

> It's still not very popular with the students. This has gotten up to worse about has popular as the lecture format.

And this like/dislike has implications:

> In MIT the only way most people evaluate a course is if the students like it or not. […] my lowest ranking ever, in terms of popularity, was in the term I thought they learned the most. And that doesn't apply here in terms of getting tenured.

Impact

The assessment study of the effects of the visualisations and the pedagogical methods associated with TEAL involved a comparison of scores between conceptual pre-tests and post-tests for the experimental (TEAL setting) and control (traditional lecture setting) groups. The results suggest that the learning gains (0-100) in TEAL are significantly greater than those obtained by the traditional lecture and recitation setting, considering the categorisation of students (high, intermediate and low achievers).

Another dimension of the study was to investigate Spring 2003 students' perceptions. They were asked to list what they considered the most important TEAL Studio elements which contributed to their understanding, giving reasons for their choices. The responses of 308 students were divided into 4 categories (Dori et al., 2004):

- Oral explanations in class;
- Technology, which included desktop experiments performed in groups, 2D and 3D visualisations, individual Web-based home assignments turned in electronically, and individual real-time class responses to conceptual questions using a personal response system (PRS) accompanied by peer discussion;
- Written problems, which included both individual problem sets given as home assignments and analytic problems solved in class workshops;
- Textbook.

The results revealed that about 40 % favoured the problem-solving method, 22% selected the technology, 22 % selected the textbook, and 16 % preferred the professor's oral explanations.

More recently, certain spaces associated to STEM universities such as makerspaces, hackerspaces, and fab labs, can provide the infrastructure for Studio teaching in STEM courses. Despite the after lessons' schedule, non-structured links to the formal curricula, and absence of instructors, these spaces can become centres for transferring the signature pedagogy of the Studio to STEM education.

3.4 Coda

What can be the distinctive features of a Science Learning Studio? In this coda, I will try to elaborate on some of these, from the review here taken from the Design Studios, the Reggio Emilia Atelier and the Physics Studio. I will organise these features in the following categories:

1. Spaces and furniture;
2. Technology;
3. Curriculum;
4. Teaching and learning activities;
5. Assessment strategies;
6. Professional culture and development.

3.4.1 Spaces and furniture

Space configuration and areas in the Studio support large groups (in the case of the Physics Studio, over 100), small groups (3) and individual work in changing teaching and learning activities, eliminating the room front.

Furniture is adequate to these changing needs, flexible and movable, or in the case of the Physics Studio, with round tables sitting 3 groups of 3 students. Servicing outlets on both the sides and middle of the Studio improve the flexibility of activities requiring electrical current. The furniture arrangement facilitates teacher circulation to support students.

There is easy access to books, tools, materials and equipment, with dimensioned storage areas to accommodate them. Mini-ateliers or prep rooms next to the main classroom are possible solutions to this, and furniture to enable storage in the Studio itself, such as cupboards, shelves and other storage solutions.

Pin-ups in bulletin boards and writing walls are common in the Studio, in the case of the Physics Studio including portable whiteboards to support collaboration and presentations to the entire class.

3.4.2 Technology

Computers and tools to prototype and model design concepts are in place for students to work. A teacher console can provide software to facilitate projection from students' laptops to the entire class. Student response systems for peer instruction or "Bring your own device" (BYOD) solutions (e.g., Socrative) can also be used.

A hybrid laptop for the teacher, with a pen, allows writing, drawing, besides the normal use of the software. It also facilitates circulation in desk crits, and allows notetaking and photographing of students' work, for documenting activities or to initiate group discussions from a concrete case. It also allows the teacher to share *floor space* with students, asking, for example, one student to demonstrate something to the entire class using the teacher's laptop, if wireless projection is in place. Applications to support drawing and class notes are useful in this context (e.g., Microsoft OneNote).

The teacher has also available a visualizer to show objects, materials, students' whiteboards or notes, documents, and an audio system, depending on the size of the class or the need of recording some aspects of the lesson. Multiple projection areas for the teacher can coexist depending on Studio size or presentation requirements.

There can be laptops dedicated to group work, per group of 3 students. With the recent developments and price tags of hybrid computers, this can be a solution for students' devices, supporting pen writing and drawing. Trolleys to store and sync laptops if uncluttering of desks for lab work is required can be useful. The use of laptops can also be useful if the teacher requires full attention from the class, he/she can ask everyone to put the lids down.

A Learning Management System can also be in place, and/or other web-based platforms to support active instruction, collaboration or assessment (e.g., groupware, digital notebooks, Office 365 Education, Apple Classroom, Google Classroom, OneNote Class Notebook Creator).

The camera, tape recorder, projector, video camera, computer and photocopying machine are instruments indispensable for recording, understanding, debating and preparing appropriate documentation of practice (Edwards et al., 2004, p. 142).

3.4.3 Curriculum

A balance between a negotiated curriculum and a formal curriculum supports development of multiple skills beyond the technical such as those identified by De La Harpe and colleagues (2009): 1) hard skills (creativity, innovation, problem-solving, critical thinking); 2) soft skills (communication, collaboration, social and ecological awareness); 3) content knowledge; 4) technology use; 5) learning approach/style; 6) professional and innovative practice; 7) reflective practice skills; 8) interdisciplinary collaboration, considering product, process and person. In the case of Reggio Emilia and Design Studios, learning goals were established as children projects unfold and needs are identified, combined with direct instruction when required.

3.4.4 Teaching and learning activities

Project based learning in the Reggio Emilia Atelier and the Design Studio plays an important role in defining activities in the Studio, departing from undefined briefs or students' interests in specific topics and real-world problems and situations.

The teacher can be engaged in desk crits, circulating among students and engaging them in reflection-in-action, provocations to extend their thinking and critique of their work, supporting collaborative reflection and co-learning with peers if needed.

Research based pedagogies are emphasised. Some examples are microcomputer-based laboratories, simulation and modelling using software, physical models or roleplay, Real World Problem Solving, advance organisers, short direct instruction moments, less than 15 minutes long, mini-quizzes, sometimes associated to peer-instruction, tangibles, ponderables, open inquiry, lab work or workshop work using multiple materials and visual languages.

Cooperative learning is also one of the distinctive activities in the Studio, with the organisation of students in groups of 3, combining students from the bottom, intermediate and top levels of attainment. The inclusion of underrepresented groups is also considered and group rotation, for example, 3-4 times per semester. Pin-ups using bulletin boards, A3 sized whiteboards per group or projection support peer collaboration and group discussion, with the resulting projects presented in collective exhibitions. Students are usually required to present their results to the class for review by instructors and peers. Some of the projects undertaken are collective and shared.

Why are we doing this? or *What am I supposed to learn from this?* are guiding questions in all the Studio lessons, engaged in the beginning and or end of each lesson. Broader communication events and out-of-the Studio activities are also part of this model, such as exhibitions, individual and collective, or public presentations.

3.4.5 Assessment

In the Studio, the weight of final exams is reduced, favouring continuous work during the term such as tests, one quiz every week, lab work and report writing, homework, individual class notes checking and data on each ponderable and tangible activities. Homework counts more than usual (20-25 %). Mid-term exams are weighted lower than usual (10-15 % each) allowing students to recover if they have a bad result in an individual test. Criterion-based grading is used instead of norm-based grading, based on the achievement of specific objectives. Self-assessment and peer assessment in group work also counts 15 % to the overall grade.

The assessment also assumes a subjective nature, using documentation to make pedagogical (or other) work visible and subject to interpretation, dialogue, confrontation (argumentation) and understanding (Rinaldi, 2006, p. 12).

3.4.6 Professional culture and development

Pedagogical pairs and work with teaching assistants are distinctive features of some of the Studio concepts reviewed. In the case of the Design Studio, invitations to experts, other faculty and external members in the end of course' public reviews demand external scrutiny from the results of professional practice.

Besides more canonical professional development, there is also in the case of Reggio Emilia, in-service training with extended support by pedagogical experts and weekly meetings to discuss practice and support reflection-in-action, using documentation of the teaching and learning activities.

3.4.7 Community links

Studio activities embed real-world practice or a design thinking methodology (IDEO, 2012) and favour relations with the wider community, professional or not, using fieldwork to engage with that same community around design challenges.

Community-based management, communal life and community presence reinforce the links between classroom and Studio practice and the professional and everyday life of community, parents and students, supporting shared governance and participation in both ways.

4. A methodology to analyse activities in the Science Learning Studio

In this chapter, my main goal is to present a methodology to analyse activities in the Science Learning Studio, departing from the development of the Pedagogical Graphic Novel and Activity Theory. The concept of Pedagogical Graphic Novel was developed as a representation of learning activities to facilitate analysis-of-practice. The analysis process was developed from Activity Theory, not new in the field of Science education (see for example Roth & Lee, 2007). I will begin by presenting the development of the concept of Pedagogical Graphic Novel and later provide a brief context on the conditions in which Activity Theory arose in Russia in the early 20th century, inevitably departing from Marx's ideas and Soviet psychology, discussing some of Systemic Structural Activity Theory's (Bedny & Harris, 2005, Bedny & Karwowski, 2007, Bedny & Chebykin, 2013) main concepts, to later introduce authors and ideas from diverse fields such as cultural studies, ethics and neurosciences, which, I will argue, demand a reframing of the main concepts, its relations and dynamics to better explain human activity. From those concepts and the dynamics of AT, I will sketch two models for the SLS: the SLS Activity Analysis Methodology and the SLS Curriculum Development Model.

4.1 Pedagogical Graphic Novels – Documenting activities in the SLS

The data collection process in several of the case studies later presented in this work evidenced a basic need in the research project: Having an activity analysis methodology demanded a tool that could document and coordinate the data collected in multiple modalities for later analysis and reporting. The time consuming and demanding integration in data scattered in paper research notebooks, audio recordings, photos, scans and digital documents made the process of capture and later analysis cumbersome. In a more focused, non-ethnographic case study, the same data capture protocol would not work. Despite the existing options of QDAS (Qualitative Data Analysis Software), both the workflow, the intermediate and final outcomes of this process remained unsatisfactory for the depth of analysis being done and the view on research ethics, participation and professional development guiding this research. To achieve a level of analysis that could be useful for teachers and students, no advanced coding needs should be necessary, and the outcomes should be manipulable by teachers and students without a research background and training in QDAS, as researchers might have.

Millar's work (2009) was not concerned with the capture for later analysis-of-practice, providing only checklists to fill in during or after a Science lesson. To find guidance to what this meta-tool might be, during a visit to the NARST Annual Conference in 2015 as invited presider to a paper session on Epistemology and Science Learning, I contacted with the STeLLA (Science Teachers Learning from Lesson Analysis, Roth et al., 2011) research project, that used video capture and editing to produce an output for lesson analysis by both teachers and teacher trainers.

Analysis-of-practice programmes provide meaningful and situated referents to which teachers can respond to, providing perceptual fidelity, cognitive fidelity (in both content, pedagogical content knowledge, classroom management and teaching strategies) and opening the possibility for metacognitive, reflexive activity on teaching practice. Roth and colleagues (2011), based on literature on analysis-of-practice programmes, claim that these can:

1. Enable teachers to see content and teaching issues embedded in real classroom contexts;
2. Engage teachers in collaborative, long-term analysis-of-practice enquiries;
3. Treat content as central and intertwined with pedagogy;
4. Focus on the specific content and curriculum teachers are teaching;
5. Organise the programme around a theory of teacher learning. (p. 118)

The obvious limitations of real-time inquiries into teaching practices require the use of artefacts of practice, such as students' work, assessment outcomes, teacher's lesson plans, notes, or video recordings. With these artefacts, it becomes possible to slow down the teaching and learning activity, revisit it multiple times and with multiple lenses, and transform it into the subject of analysis outside the classroom (Roth et al., 2011, p. 118).

Following this line, despite its specific focus on professional development, one of the early prototypes to document activity in the SLS integrated the data capture combining mostly video and observation notes taken with two mobile devices (tablet and smartphone) during a lesson. These two feeds were wirelessly transmitted to a computer that was screen recording those two feeds picture-in-picture, and if necessary, the exploration of documents used during the lesson.

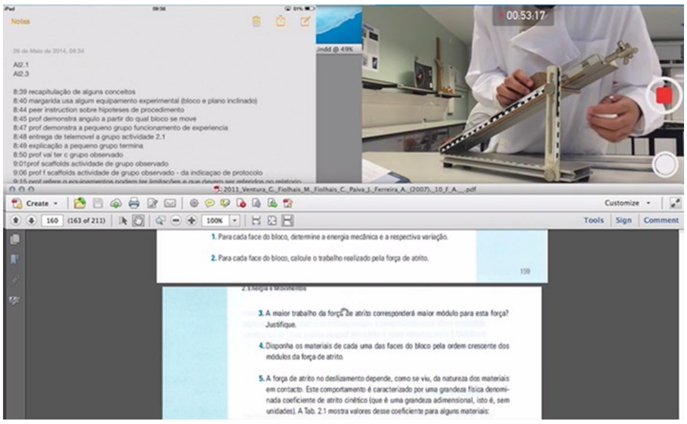


Figure 4.1 – Snapshot of multiple data capture sources of a lesson, combining notes and video from two mobile devices streaming to the computer producing the screen recording. There is also a document opened related to the lesson providing context to the notes and video

It was soon realised that the effort involved in this analysis and the goal of the case studies in the overall research project were misaligned:

1. The data and processing-intensive workflow involved in video capturing and analysis made the process slow;
2. Producing a practical output from this analysis by teachers or to engage teachers and students in a reflective dialogue took too much time after the actual observation;
3. The format to communicate both activities and analysis to a broader audience was mostly digital, ignoring paper formats.

This workflow was put aside, and new prototypes were planned, following some ideas based on previous work in capturing practice in PE's intervened schools.

In 2010, a country-wide teacher training programme took place for 110 teachers teaching in all of Parque Escolar's intervened or soon to be intervened schools, entitled "Using the new Science laboratories". One of its goals was to design activities that promoted active learning, aligned with the view on teaching and learning in the Science Learning Studio. One of the proposed activities required trainees to produce a photographed protocol of a practical activity, to later be used in lessons with students, so that they could infer the procedure and the materials involved, providing prompts with perceptual fidelity to support enquiry practices that coordinated the domain of objects and observables with the domain of ideas. (Millar, 2009)

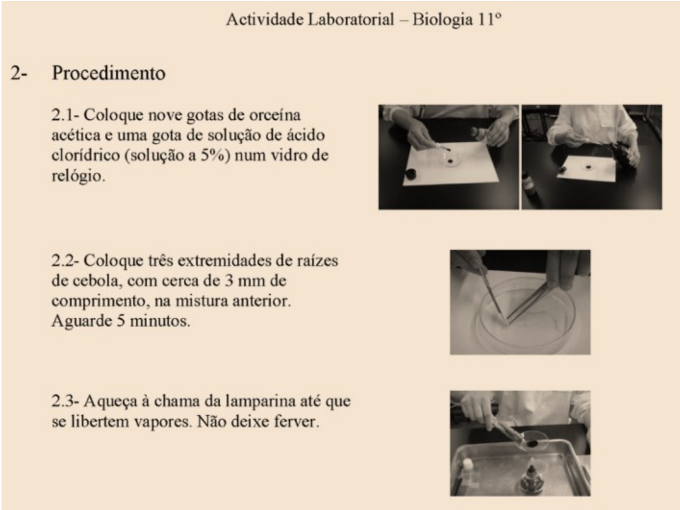


Figure 4.2 - Excerpt of a practical activity protocol using images. In this teacher version, there is text added but in the student version, no text was included.

Later, in a classroom observation in one the intervened schools in the Lisbon region, and to better communicate to teachers the dynamics of activities in the new spaces, after a photographic recording of a lesson, Prof. Vitor Teodoro combined the photos with a brief explanation of the represented activities, in a format close to the storyboard.

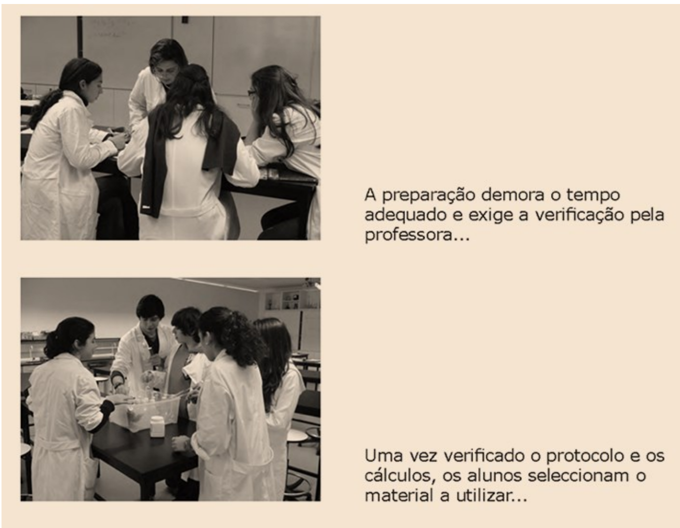


Figure 4.3 – Storyboard of an activity taking place in a Chemistry lesson in a SLS in 2010

With the goal of extending the same rationale to other activities not essentially practical, and to facilitate the production and dissemination of these storyboards, I began some experiments with photographing lessons, later processed with filters to anonymise the participants, and then composed graphically into a matrix, adding another layer of information on the dynamics of participants and their use of space, objects and other resources used during the lesson.

Figure 4.4 – A storyboard showing only two vignettes, in an overall matrix format, of an activity made in a theoretical lesson on Cinematics in year 10 Physics (2010)

The rationale for this matrix was that it could communicate the interaction between teachers, students, space and tools, becoming an economic and easily readable format for 45-60 minutes lessons, and that it could be printed in 2-3 pages, with each page representing approximately 30 minutes of class time. This was thought to be helpful in communicating the main aspects of a lesson to other teachers using the SLS. However, it still demanded much time to compose and advanced software skills to produce.

I revised the concept of storyboard and compared it to several alternatives, later reframing it for a Science Education context as Pedagogical Graphic Novel. Pedagogical due to its focus on teaching and learning activities; Graphic due to its perceptual fidelity to the activity; and Novel due to its conceptualisation by Bakhtin (1982, 1990) as a literary genre that is adaptable due to its lack of canon and that affords an aesthetical, dialogical relation between the author and its hero.

I propose a tentative definition as: Pedagogical Graphic Novels are representations of intentional learning activities with a certain degree of perceptual fidelity, real or simulated, that make explicit the structure and trajectory of the said activities.

Reflecting on this broader approach, several applications emerged for this instrument:

1. For researchers, teacher trainers, educators and peers to record and analyse what is happening in the SLS;
2. For researchers to communicate research-based pedagogies;
3. For teachers to record their classes as practitioners, and if taken beyond that, providing opportunities for reflective practice and improvement;
4. For teachers and students to use them in teaching and learning activities to improve dialogue and communicate activities in the SLS or classroom.

There was still the need to design a workflow easy enough to sync the several data types acquired during the lesson (notes, photos, audio/video and files), allow analysis and generate a flexible output, in digital and paper formats, keeping its participatory and collaborative nature.

The first step was to provide one student with a tablet with internet access and instruct him/her to capture classroom activity, by taking photos and writing captions describing the tasks on a Microsoft OneNote page. I was connected to this same page in another device, that synced all the changes made by the student in real-time.

Figure 4.5 – Screenshot of the capture being done by a student in a practical lesson using a tablet in Microsoft OneNote

In this way, I could follow the student's capture in real-time, and give him/her just-in-time feedback on the relevance and quality of the capture and accompanying notes. By the end of the lesson, the outcome would be reviewed with the student, cropping images in OneNote to focus its key aspects and composing them into a Graphic Novel template.

The audio recording done in OneNote was synced with the notes taken so that when the audio was played, the text would be highlighted and vice-versa. There were also links from parts of this novel to data collected in other formats (for example, PDF files or PowerPoints used in class), or transcriptions of dialogues, providing more detail to the graphic novel.

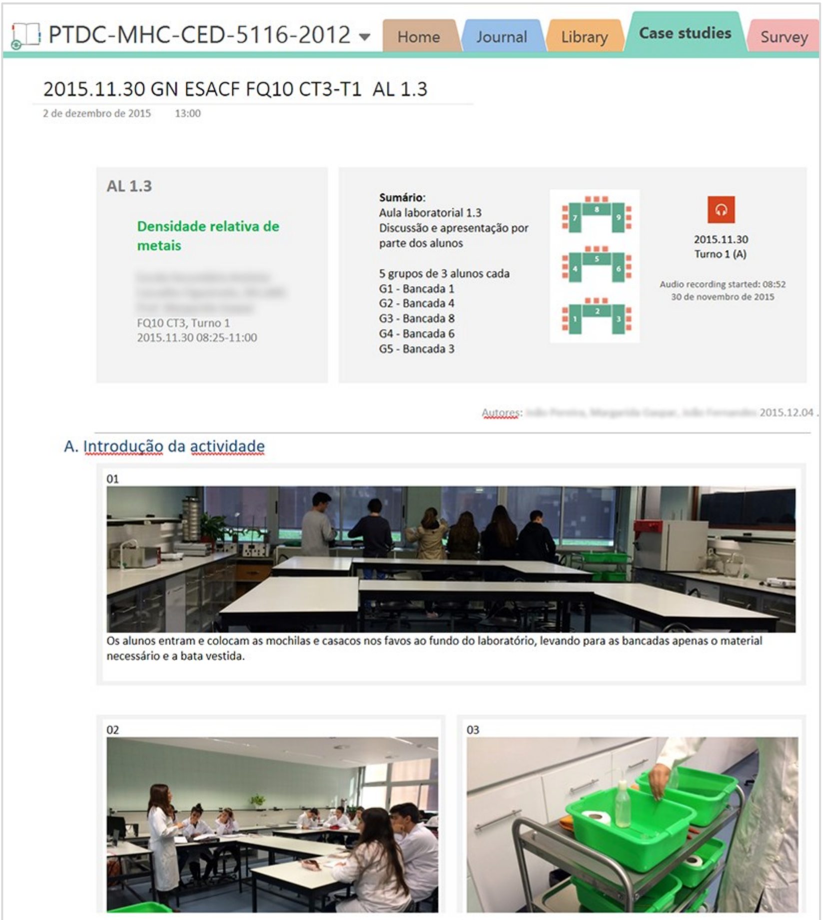


Figure 4.6 – Screenshot of the first vignettes of the Pedagogical Graphic Novel

This first draft of the Pedagogical Graphic Novel was then edited collaboratively with the teacher after the lesson. Besides correcting sequences, photo framings and descriptions, myself and the teacher identified issues that could be raised when discussing the novel with the class, related to the activity's goals, in this case mainly of verification of theory (measurement of physical quantities to calculate the density of a known metal and comparing it to the theoretical value; use of significant figures), and development of correct procedures in the laboratory (manipulation of materials and equipment, types of errors, data organisation).

In the lesson after this editing process, the Pedagogical Graphic Novel was projected for the entire class, and collectively analysed and reviewed, with the vignettes framing the discussion. During the discussion, more changes were done to the novel.

This workflow finished with publishing the graphic novel in PDF and paper formats. The novel had as authors the student, the teacher and the researcher. With an instrument to record activity in place, now the need was of an instrument for activity analysis.

4.2 Active learning environments for Science Education – The path not taken to analyse activities in the SLS

Searching for a tentative framework to analyse activities in the SLS, I began to explore the literature on active learning environments as used by SCALE-UP in the definition of its acronym. This led me to review some of the literature on learning environments more broadly (for example Fraser, 2002) and its instruments to measure classroom and laboratory environments, without any meaningful *encounters*. I also reviewed the literature on several themes of the kind "PUT YOUR ADJECTIVE HERE_Learning environments", focused on characterising an overarching solution to classroom instruction, mostly from the point of view of instructional design, such as powerful learning environments (De Corte, Verschaffel, Entwistle, & van Merriënboer, 2003), authentic learning environments (Herrington & Oliver, 2000; Roth et al., 2008), open learning environments (Hannafin, Land and Oliver, 1999), rich environments for active learning (Grabinger & Dunlap, 1995) or constructivist learning environments (Wilson, 1995). The lack of a common theoretical framework was not helpful to my goal of finding a framework for analysis. The work of project Labwork in Science Education led by Marie-Geneviève Séré (Psillos & Niedderer, 2003), Millar (2009) and Abrahams (2011) provided an empirical approach to the problem, but again, I was not convinced by the theoretical framework guiding this analysis. Engestrom (2009) in his work apparently dealt with the same problem:

> The notion of learning environment is usually presented with an attribute. We have dynamic learning environments (e.g., Barab & Kirshner, 2001), innovative learning environments (e.g., Kirshner, 2005), powerful learning environments (e.g., De Corte, Verschaffel, Entwistle, & van Merriënboer, 2003), collaborative learning environments (e.g., Beers, Boshuizen, Kirshner, & Gijselaers, 2005), networked learning environments (e.g., Wasson, Ludvigsen, & Hoppe, 2003), smart learning environments (e.g., Dodds & Fletcher, 2004), real-life learning environments (e.g., Järvelä & Volet, 2004), authentic learning environments (e.g., Herrington & Oliver, 2000), and many many more. Common to this plethora of attributes is that they are positive, optimistic, promising, and promotional. They seem to be designed to serve the selling of a wishful image of future learning in which all good qualities of human interaction come true (…). The static and hierarchical nature of many models of learning environment corresponds to what Davydov (1990) calls empirical generalization (Engestrom, 2009, pp. 18-19).

His argument then follows that Activity systems (as in Cultural Historical Activity Theory) might be a helpful theoretical concept as the centerpiece and unit of analysis in research in computer-supported collaborative learning. However, after reviewing analysis of activities in educational contexts using this theoretical framework (e.g., Roth et al., 2008; Yamagata-Lynch, 2010; Bedny, 2015), I remained unsatisfied: unclear concepts across authors, too much complexity for daily use by practitioners, no meaningful links to my own research work and goals. Despite this, I remained faithful to AT as a departing point to help make sense of a complex problem. What ontology guides activity theory? What ethics is there? What epistemology? What implications for teaching and learning methodologies and activity analysis? Could it provide answers to these ambitious questions?

Probably not. Even so, maybe from ingenuity, I took my chances and I will present in this chapter my findings on Activity Theory, knowing that these are *sketchy*, limited, overly ambitious and my skills are limited to the task. But if not now, when could I have done this kind of thinking? Years of searching in the dark, for a truth that one feels, but cannot express; the intense desire and the alternations of confidence and misgiving, until one breaks through to clarity and understanding, are only known to him who himself has experienced them, as Einstein has put it. This is my account of my years of searching in the dark until one breaks through to clarity and understanding.

4.3 From Marx to the soviet psychology to the Russian lineage of Activity Theory

The differentiation of Psychology as a field in early XXth century Russia was achieved by researchers and practitioners from fields such as philosophy and medicine. Physiological psychology and more pluralistic approaches, combining Wundtian experimentalism, introspective methods and phenomenological accounts, coexisted at the time for behavioural research, attentive to European and American works, discussed in scientific meetings and journals and giving birth to research programmes and experimental methods in several institutions.

Chelpanov, for example, the founder of the Lydia Shchukina Psychological Institute in Moscow in 1912, had a more pluralistic approach, critical of some of Bektherev's students, from the Institute of Brain Research in Petrograd. These were trying to discredit the notion of consciousness to establish an objective psychology based on behaviour and neurophysiology, following recent discussions between American behaviourists and phenomenologists (Kozulin, 1984).

After the Bolshevik revolution and the splitting of Russian Science in several fields through the creation of institutions under the direct supervision of the Communist Party, an apparent peace between worldviews was maintained but dramatically changed in 1922-23, with many Russian intellectuals, including those from the field of Psychology, being briefly imprisoned and later exiled (Kozulin, 1984).

These Psychology Wars between two views, fed by the ideological climate of the new-born Soviet Union, resulted in the loss of the pluralistic side, with Chelpanov's purge in 1923 and the physiological approach gaining the regime's trust and support. The psychophysics and physiological psychology, with Pavlov's "higher nervous activity" as a well-known representative, were put under the rubric of behaviourism in the US for example, but in the Soviet Union, the research programme of several psychologists was on how behaviour was correlated with brain functioning (Bedny & Karwowski, 2008; Kozulin, 1984).

The known scheme Stimulus → Response schema, representing an influence on the subjects' receptor systems that originates a response (objective or subjective) evoked by that same influence, created difficulties in soviet psychology, due to the lack of the active role of the subject in the process. Rubinshtein, trying to solve this limitation, emphasised the fact that the effects of external influences depend on how the subject interprets them, with the maxim "External causes act through internal conditions" (Wertsch, 1981, p. 42).

Vygotsky first public recognition as a psychologist took place in 1924, in the second Psychoneurological Congress, challenging the mechanistic and naturalistic attempts to reduce human activity to reactions and reflexes (Kozulin, 1984, p. 18). Vygotsky's introduction to the problem of development of higher mental functions takes on the contrast between the primitive and the cultured man to grant importance to the role of culture in the development of behaviour. In his sociocultural theory of the development of the mind, primitive and modern man are of the same biological type, that is, without significantly different physiological devices, but the later develops higher mental functions due to interactions with his social and cultural environment (Vygotsky, 1987).

Activity theory developed in an attempt to provide unification in Russian psychological theory, integrating physical and phenomenological accounts, in which cultural-historical development and social interactions are interrelated to brain functioning. That is, of course, a grand challenge, a kind of theory of everything for human cognition, motivation and behaviour.

My interpretation of the literature on General Activity Theory (GAT), Cultural-Historical Activity Theory (CHAT) and Systemic-Structural Activity Theory (SSAT) is that there is no agreement among experts in the field in definitions of concepts, structure or graphic representations (Wertsch, 1981;

Kozulin, 1986; Leontev, 1981; Engestrom et al., 1999; Kaptelinin & Nardi, 2006; Bedny & Harris, 2005; Bedny & Karwowski, 2007; Bedny 2014, 2015), a view that is shared by Bedny & Chebykin (2013). I cannot find an agreed ontology, epistemology, ethics, methodology or even terminology. So, can activity theory be helpful in my effort to develop a SLS Activity Analysis Methodology?

4.3.1 An introduction to some of the concepts of Activity Theory

General Activity Theory has been mainly introduced to the international community in two publications: Leontev's (1978) book and a collection of articles edited by Wertsch (1981). It does not provide any specific methods of analysis of activity, such as Cultural Historical Activity Theory and its Scandinavian lineage (Engestrom et al., 1999), more descriptive, or Systemic-Structural Activity Theory (SSAT, Bedny & Karwowski, 2007), more concerned with work analysis, ergonomics and the predictive aspects of the theory.

Activity can be defined for now as a self-regulated system that integrates cognitive, behavioural and motivational components and is directed toward achieving a conscious goal (Bedny & Karwowski, 2007). This definition can be represented by the following schema:

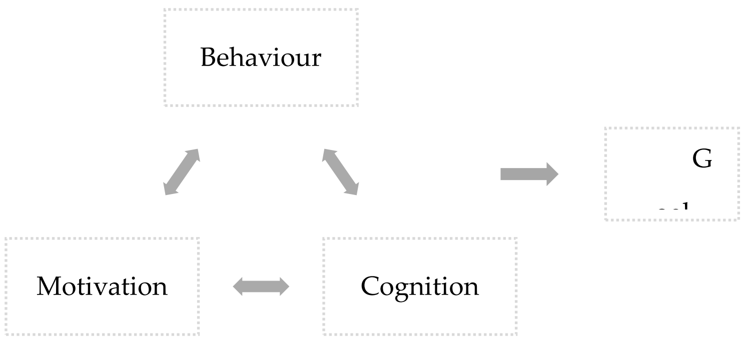


Figure 4.7 – Schema of Activity (adapted from Bedny & Chebykin, 2013)

Engestrom, in his work Learning by expanding (1987) and his Activity-theoretical approach to developmental research, departed from the structure of activity of animals, characterised by the interrelations between individual, environment and population. In the case of humans, he considers that there are ruptures in each of the sides of this triangle: 1) the top side of individual survival (doing alone), is ruptured by the emerging utilization of tools; 2) the left-side of social life (being together) is ruptured by collective traditions, rituals, and rules, originating at the crossing of adaptation and mating; and 3) the right side of collective survival (doing together) is ruptured by division of labour, influenced by the practices of breeding, upbringing, and mating (Engestrom, 2015, pp. 60-61).

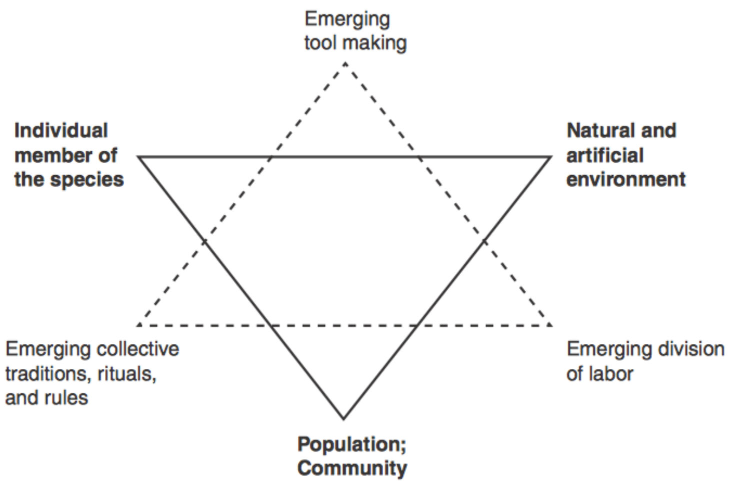


Figure 4.8 – Structure of activity in transition from animal to human (Engestrom, 2015, p. 61)

What used to be adaptive animal activity is transformed into consumption and subordinated to the three dominant aspects of human activity – production, distribution, and exchange (or communication):

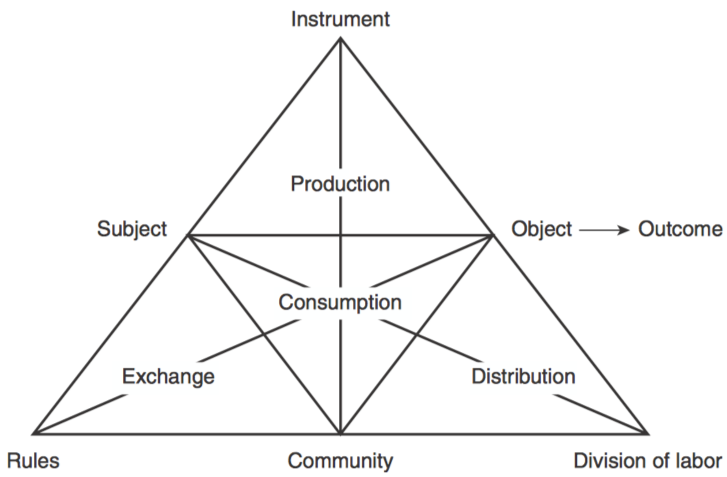


Figure 4.9 – The structure of human activity (Engestrom, 2015, p. 63)

Bedny & Karwowski (2007), from a background on analysis of human work, propose a different structure of human activity:

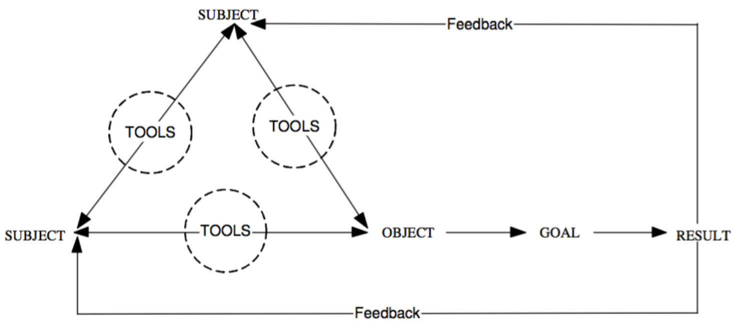


Figure 4.10 – Structure of human activity according to Bedny & Karwowski (2007)

In this interpretation, there is an emphasis on the goal of Activity, leading to a Result, regulated by Feedback mechanisms, an influence of the concept of self-regulation from the field of Cybernetics. The broken circles in the figure indicate that subject–object interaction may be either direct or using tools, following the interpretation of Vygotsky. By the same token, the Subject-Subject interaction may be direct (speech, gesture) or instrumentally mediated (e.g., telephone, email). In both object- and subject-oriented actions, direct interaction should not be taken as implying a complete absence of mediating instruments; rather, in such cases, the subject employs "internal" tools (Bedny & Karwowski, 2007, pp. 39-40).

The following table synthesises the definitions of the most important terms in SSAT.

Table 4.1 – Terms and definitions in SSAT (Bedny & Chebykin, 2013)

Term	Definition
Object, subject-object relationship	An object of activity that can be material or mental (symbols, images, etc.) is something that can be modified by a subject according to the activity goal. There is not just a subject → object interaction but also a subject ↔ subject interaction. In general AT, the object of study is Activity and the main units of analysis are cognitive and behavioural Actions. Smaller units of analysis are psychological operations.
Units of activity analysis	SSAT utilizes the following units of analysis classified according to the developed principles: cognitive and behavioural actions and operations, functional micro- and macroblocks, and operators and logical conditions. Actions and operations are utilized in morphological analysis. Functional blocks are utilized in analysis of activity self-regulation. Operators and logical conditions are utilized in algorithmic description of activity.
Task	Task is a goal given under certain conditions. The work process consists of several tasks the performance of which is restricted by time constraints. Task is a type of activity that requires achievement of a certain goal in specific conditions. A general hierarchical scheme of activity includes four levels: work activity–task–action–operation. Task consists of actions and can be described as a logically organized system of cognitive and behavioural actions directed to achieve the goal of a task.

Term	Definition
Goal, goal-motives relationship	Goal is a conscious desired result of the subject's own activity. Goal cannot be considered as an externally given standard. It should be interpreted, accepted, and formulated by a subject. Motive(s) → goal creates a vector that lends activity a goal-directed character. Motives are energetic, whereas goals are cognitive components of activity. Activity during task performance can have several motives and only one overall goal of task. The more intensive the motives are, the more effort a subject spends to reach the goal of task.

I could not make sense of different definitions for the same terms in the several AT varieties, theoretical or practical, and subsequently, devise a practical application to the analysis of teaching and learning activities in the SLS. So, my approach was radical. I resorted to primary sources to understand the ontogeny of Activity Theory and its main concepts, starting from Marx and Vygotsky and later to the main researchers in Activity Theory and all its lineages, combining literature on cognition (Carey, 2009; Damásio, 2010; Barsalou, 2008), epistemology (Bohr, 1949; Carey, 2009), ethics (Bakhtin, 1982, 1990, 1993), to define my own meanings of the terms and if necessary, use new ones to make sense of the theory. I will provide in the following table an advance organiser of terms and definitions, that will then be presented in the next sections.

Table 4.2 – Terms and definitions in my account of Activity Theory

Term	Definition
Activity	The main object of study, is represented by a Trajectory from an initial to an end state. Can be subdivided into tasks, which are subdivided into actions, and later in operations.
Subject	The reference individual performing the Activity.
Other	That which is modified by a Subject (and modifies the Subject in the process) in Activity. Can be human or non-human, concrete or abstract, depending on the scale of Activity (sensory-perceptual, conceptual, meta-conceptual).
Apparatus	The mediator between the Subject and the Other, can be human or non-human, concrete or abstract, depending on the scale domain of Activity.
Scale domain	Domain of activity, for example sensory-perceptual, conceptual, meta-conceptual, etc. Higher domain' activity always requires lower domain' activity but the opposite is not necessarily so.
Motive	Interoceptive signification of the Activity's Trajectory.
Programme	Proprioceptive signification of the Activity's Trajectory.
Goal	Exteroceptive signification of the Activity's Trajectory.

4.4 Activity as a solution for the Subject-Object dualism (the ontological problem)

This section will begin with a discussion of some of Marx's reflections on the nature of the relation between subject and reality and on how these relate to some of the concepts in Activity theory, particularly Subject and Object.

4.4.1 The nature of the relationship between Subject and Object in human activity

The discussion on the nature of students' learning is not new in education. Dewey, Ausubel and many others defended the active role of the student in his own learning. This discussion resembles Marx's views on the emergence of subjectivity, that is, consciousness, in contrast to Feuerbach's interpretation.

In his work Theses on Feuerbach (1995), Marx shows his disagreement with the existing materialism's discourse which positions reality as an object of contemplation, external to the subject:

> The chief defect of all hitherto existing materialism – that of Feuerbach included – is that the thing, reality, sensuousness, is conceived only in the form of the object or of contemplation, but not as sensuous human activity, practice, not subjectively. Hence, in contradistinction to materialism, the active side was developed abstractly by idealism – which, of course, does not know real, sensuous activity as such. (p. 1)

This kind of materialism is, in his conception, flawed, reinforcing the distinction between sensuous objects and thought objects and conceiving human activity as only subjective:

> Feuerbach wants sensuous objects, really distinct from the thought objects, but he does not conceive human activity itself as objective activity. (Marx, id.)

Leontev's view on Marx's critique is that according to the materialistic view of Feuerbach, the emergence of subjectivity, that is, consciousness, is a result of the impact objects have on the cognizing subject, more precisely, through his sensory apparatus:

> When speaking of the notion of contemplation found in previous forms of materialism, Marx had in mind the fact that proponents of these earlier schools viewed consciousness as emerging only as a result of the impact objects have on the cognizing subject, on its sense organs, but not as a result of the development of the agent's activity in the object world. Thus, old materialism separated consciousness from sensual activity. It separated it from man's living, practical connections with the surrounding world. (Wertsch, 1981, p. 10)

A schema that can resume Feuerbach's view is proposed below:

[Subject ← Reality/Thing/Sensuousness/Object in the subject's contemplative activity] → a changed Subjectivity/Consciousness

Figure 4.11 – A schema resuming human contemplative activity of reality, where subjectivity/consciousness results on the impact of Objects (O) on the Subject (S) through its senses. For the sake of simplification, alternative terms for *external* reality were here replaced by Object. This is a philosophically charged concept, used in Activity Theory.

Marx claims that the relationship between subject and reality is active in practical-critical or revolutionary activity. This means that the human subject in activity within reality actively changes his/her subjectivity and in the process, changes reality itself. And the point is to change it:

> The coincidence of the changing of circumstances and of human activity or self-changing can be conceived and rationally understood only as revolutionary practice. (Marx, id.)

A proposition and schema that can resume Marx's view are proposed below:

The relationship between Subject and Object in the subject's revolutionary/practical-critical activity → a changed Subject/Subjectivity/Consciousness and a changed Object/Reality:

Figure 4.12 – A schema resuming human revolutionary/practical-critical activity, in which the active relationship between Subject (S) and Object (O) changes both.

As Leontev has put it,

> Viewed from this perspective, activity emerges as a process of reciprocal transformations between subject and object poles. According to Marx, in production the individual is objectivized, and in the individual the object is subjectivized. (Wertsch, 1981, p. 46)

4.4.2 The intra-active nature of the relationship between Subject and Object

At this point, some ontological considerations are required. Is the Subject different from Reality, ontologically speaking? Are Subject and Object ontological units prior to activity? Are there any Subject and Object prior to Activity and then, through Activity, they become reciprocally transformed? Barad's agential realist proposal provides an interesting answer to this question:

> (…) the primary ontological unit is not independent objects with inherent boundaries and properties but rather phenomena. In my agential realist elaboration, phenomena do not merely mark the epistemological inseparability of observer and observed, or the results of measurements; (…) That is, phenomena are ontologically primitive relations without preexisting relata. The notion of intra-action (in contrast to the usual "interaction," which presumes the prior existence of independent entities or relata) represents a profound conceptual shift. It is through specific agential intra-actions that the boundaries and properties of the components of phenomena become determinate and that particular concepts (that is, particular material articulations of the world) become meaningful. Intra-actions include the larger material arrangement (i.e., set of material practices) that effects an agential cut between "subject" and "object" (in contrast to the more familiar Cartesian cut which takes this distinction for granted). That is, the agential cut enacts a resolution within the phenomenon of the inherent ontological (and semantic) indeterminacy. In other words, relata do not preexist relations; rather, relata-within-phenomena emerge through specific intra-actions. Crucially, then, intra-actions enact agential separability - the condition of exteriority-within-phenomena. (Barad, 2007, pp. 139-140)

The claim here is, if Barad's construct Phenomena is replaced by that of Activity, then it does not make sense to refer to separate Subjects and Objects suspended in space and time, waiting for Activity to then become transformed. In other words, Subject and Object are inextricably co-constituted in continuous Activity, and the idea that will be later developed in this chapter when dealing with the epistemological aspects of human Activity.

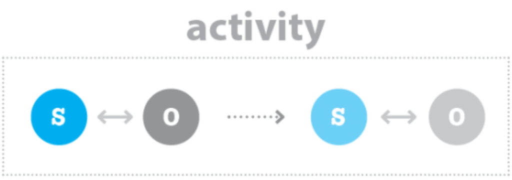


Figure 4.13 – A schema resuming the co-constitution and transformation of Subject (S) and Object (O) within human Activity

4.4.3 Ethical activity or why the Object should be conceptualised as Other

From the standpoint of human Activity, Object is technically and ethically troublesome. The term, originates in the neuter past participle of the Latin *obicere*, from ob- 'in the way of' + jacere 'to throw' (Oxford Dictionaries, 2016), embedding in language a particular ontology that considers Object, on one side, a thing external to the Subject, and on the other, a *thing* to be *thrown* by the Subject, as if a manifestation of an inferior ontological status. If we consider that from the frame of reference of the Subject, any other human subject, natural or cultural object, is what actually make possible the existence of this same Subject in the first place, this *object* must have the same ontological status than the Subject.

In several of his works (1990, 1993), Bakhtin deals with this conflict in the relationship between the author and the hero that the author constructs and relates to during the writing process.

An aesthetic activity presupposes a dialogic relation between Subject and Other that respects the uniqueness, non-repeatability and unfinalisation of both Subject and Other in the once-occurrent Being:

> The first step in aesthetic activity is my projecting myself into him and experiencing his life from within him. I must experience — come to see and to know — what he experiences; I must put myself in his place and coincide with him, as it were. (…) But is this fullness of inner merging the ultimate goal of aesthetic activity, for which outward expressedness is only a means and performs only an informative function? Certainly not. Aesthetic activity proper has not even begun yet. (…) Aesthetic activity proper actually begins at the point when we return into ourselves, when we return to our own place outside the suffering person and start to form and consummate the material we derived from projecting ourselves into the other and experiencing him from within himself. And these acts of forming and consummating are effected by our completing that material (that is, the suffering of the given human being) with features transgredient to the entire object-world of the other's suffering consciousness. These transgredient features no longer have the function of informing but have a new function, the function of consummating. (Bakhtin, 1990, p. 38)

The Bakhtinian Subject can only happen dialogically, in an answerable and responsible act toward every Other, be it other human or the world. Bakhtin emphasises the Other as human in his treatment of the relationship between author, hero and reader, but this otherness that is a condition for subjectivity extends beyond the human to the *natural* world:

> I calibrate the time and place of my own position, which is always shifting, in the existence of other human beings and the natural world by means of the values that I articulate in deeds. Ethics is not abstract principles but the pattern of actual deeds I perform in the event that is my life. My self is that through which such performance (…) answers [to] other selves and the world from the unique place and time I occupy in existence. (Clark & Holquist, 1986, p. 64)

To express this ontological democracy of Subjects and Objects, my proposal is to replace Object by Other as an improved construct, that embeds Bakhtin's view of aesthetics and ethics in Activity, represented in the following schema.

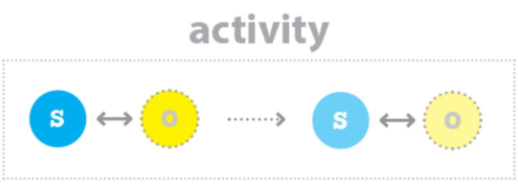


Figure 4.14 – A schema resuming the co-constitution and transformation of Subject (S) and Other (O) within human Activity

4.4.4 Human activity is always mediated through an Apparatus

Marx, in his work Capital, speaks of Instruments of labour as mediators between the Subject and the Subject of labour:

> An instrument of labour is a thing, or a complex of things, which the labourer interposes between himself and the subject of his labour, and which serves as the conductor of his activity. He makes use of the mechanical, physical, and chemical properties of some substances in order to make other substances subservient to his aims. Leaving out of consideration such ready-made means of subsistence as fruits, in gathering which a man's own limbs serve as the instruments of his labour, the first thing of which the labourer possesses himself is not the subject of labour but its instrument. (Marx, 1982, p. 199)

Vygotsky, in his work Development of mental higher functions (1987, p. 79), reifies this relation in psychological terms, departing from his experimental work with children reacting to *direct* and mediated stimulus. Vygotsky differentiates higher forms of behaviour as those which instead of *direct* operations of the Subject and the Other, use mediating Tools or Signs to master behaviour, replacing one (Figure 4.15a) by two associative connections (Figure 4.15b):

> Without going into a detailed analysis of the experiment, we will turn at once to a generalized schematic consideration of what occurred in this case. (…) With a neutral formation of a connection, a direct conditioned reflex connection is established between the two points A and B. With a mediated establishment of the connection, instead of one, two other connections are established that lead to the same result, but in different ways. (Vygotsky, 1987, p. 80)

This view can be resumed in the following schema:

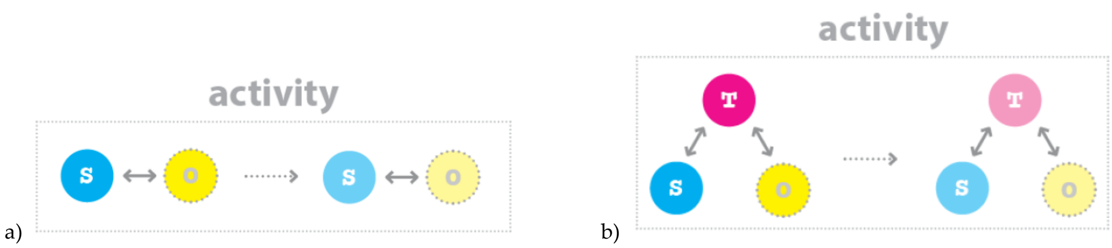


Figure 4.15 - A schema resuming the a) direct operation of Subject (S) and Other (O) within Activity in lower mental functions; and b) the mediating role of Tools or Signs (T) between Subject (S) and Other (O) within Activity in higher mental functions

I will now argue that any mental function, either *higher* or *lower*, is always a mediated activity. There is no structural difference between direct or sign-mediated activity. *Direct* operations always use a Tool/Sign (the body dispositions connected to dispositional mechanisms in the brain). To begin constructing this explanation, Vygotsky's own argument for mediated activity exploring Jennings concept of activity will be preliminary discussed and later Bohr's discussion with Einstein on epistemological problems in atomic physics (1949) will show the inevitability of the Apparatus in mediating the relation between Subject and Other.

Direct operations are mediated operations

Vygotsky's introduction to the problem of development of higher mental functions takes on the contrast between the primitive and the cultured man to grant importance to the role of culture in the development of behaviour. Primitive and modern man are of the same biological type, that is, without significantly different physiological devices, but the later develops higher mental functions (Vygotsky, 1987, pp. 19-20).

He then resorts to Jennings' concept of systems of activity to state that the organs and organisation of the animal, contrary to humans, limit the forms of activity of the individual. In the case of humans, the limits established by the organs and organisation can be surpassed because "he can extend the radius of his activity limitlessly by using tools" (Vygotsky, 1987, p. 20). The tool as such modifies the natural activity of the organs and generates new systems of activity of mental functions (p. 63) *but* it requires those same organs to provide the mediating function. Tools don't function in a void. And in this sense, direct operations or instrumental operations are necessarily mediated by the organs, or more precisely by body dispositions, through proprioceptive modalities.

Bohr's discussion with Einstein on epistemological problems in atomic physics

Bohr insists on viewing phenomena as the overall interaction between observer, experimental arrangement and observations. In his discussion with Einstein on epistemological problems in atomic physics, Bohr warns

> (…) especially against phrases, often found in the physical literature, such as 'disturbing of phenomena by observation' or 'creating physical attributes to atomic objects by measurements.' Such phrases (…) are at the same time apt to cause confusion (…) As a more appropriate way of expression I advocated the application of the word phenomenon exclusively to refer to the observations obtained under specified circumstances, including an account of the whole experimental arrangement. (Bohr, 1949, p. 25)

In this sense, measurements do not reveal objective, pre-measurement properties of objects independent of phenomena.

> Indeed, it became clear that the whole edifice of classical physics represents an idealization applicable only to phenomena in the analysis of which all actions are sufficiently large to permit the neglect of the individual quantum. While this condition is amply fulfilled in daily-life events, we meet in the exploration of the world of atoms, made possible by modern development of experimental technique, fundamental regularities which reject

causal analysis and even pictorial representation. In quantum physics, we can in fact no longer uphold customary ideas of properties and behaviour of the objects under investigation as separate from the interaction between such objects and the measuring instruments [the apparatus], indispensable for the definition of the circumstances under which the phenomena occur. (Favrholdt, 1999, p. 387)

Two aspects of activity can be drawn from this discussion: 1) human Activity is always mediated by an Apparatus; 2) the Subject is inevitably part of phenomena (Activity) in both the mental and practical domains, in his mental representations of ontological zoos (Ogborn, 2008), of imagined Apparatuses to test those representations and on accepting its veridicality with the sensory, practical domain of its Activity (and vice-versa). In human Activity, including scientific, the human subject is inescapable. Is objectivity then possible?

Let us start with the implication from this view that the Apparatus is an ontological unit as much as Subject and Other and must be accounted for in any Activity. A schema that resumes this view is presented below, replacing the Tools/Signs drawn from Vygotsky's work.

Figure 4.16 - A schema resuming the mediating role of the Apparatus (A) between Subject (S) and Other (O) within Activity

If we can't exclude the Subject from an account of Activity, is objectivity, as in the sense of not requiring subjectivity, possible? Is objectivity, subjectivity-independent, relegated to a kind of Marx's commodity fetishism, as a reification of the Subject's ontological zoos, deprived of their bearer? If we depart from the assumption that humans are nature that became conscious to itself, and that our representational activities are also natural, having an equal status to other natural phenomena, if we can understand human Activity, we can understand nature's Activity. And to understand human Activity, I will now try to address the epistemological problem of human activity.

4.5 Activity as a solution for the sign-signification dualism (the epistemological problem)

We are born with innate representational repertoires that allow us to function and make sense of the world and ourselves. The empiricist-rationalist views on this matter centre around the essential problem of whether these innate, primitive representational repertoires are at the scale of practical, sensory representations (the empiricist view) or at the scale of mental, conceptual representations (the rationalist view). Concerning the empiricist view, Carey (2009) describes it as follows:

> It was important part of the empiricists' theory that they took the primitive concepts to be sensory. They assumed that sensory representations are the output of innate sense organs, and that sensation provides causal connections between entities in the world and our representations of them. (p. 492)
>
> The views of James, Quine, and Piaget are related in their assumption that a major distinction can be made between sensory representations, on one end of a continuum, and conceptual representations, on the other end. All three theorists posited that sensory/perceptual representations are developmentally primitive, and that uniquely human mental capacities underlie the developmental processes through which sensory/perceptual representations are transformed into conceptual ones. Sensory representations can, of course, be distinguished from perceptual ones, (…) but these writers did not draw a clear distinction between them. For present purposes, the important contrast is between sensory/perceptual representations, on the one hand, and conceptual ones, on the other. (p. 6)

In her work The Origin of Concepts (2009), Carey proceeds to review the evidence that supports that by 2 to 5 months of age, infants can represent objects as existing *independently* from themselves. She is convinced of at least a partial rationalist interpretation of cognition, as these observations cannot be explained from sensory primitives, intermodal correspondence, or cultural construction but only by conceptual primitives that are innate, constructed through natural selection (2009, p. 69). One of her main thesis is that an architecture of the mind, besides innate sensory representations, must account for conceptual primitives articulating innate perceptual input analysers, in what she calls core cognition.

> Core cognition has several properties. First, core cognition has rich integrated conceptual content. By this I mean that the representations in core cognition cannot be reduced to perceptual or sensori-motor primitives, that the representations are accessible and drive voluntary action, and that representations from distinct core cognition systems interact in central inferential processes. Second, core cognition is articulated in terms of representations that are created by innate perceptual input analyzers. Natural selection has constructed these analyzers specifically for the purpose of representing certain classes of entities in the world, and this ensures that there are causal connections between these real-world entities and the representations of core cognition. Third, the perceptual analysis devices that identify the entities that fall under core domains continue to operate throughout life. (Carey, 2009, p. 67)

Human representational devices, both at the sensory-perceptual and conceptual domains, are the product of different time scales: biological evolution of the species through natural selection, cultural-historical development (and selection) and its interaction with natural selection (Hubbard et al., 2016), providing increasingly complex cultural apparatus (language, books, artistic works, other culturally complex individuals, institutions and activities, etc.) to the individual's life activity. Vygotsky was a central figure in calling the attention to the role of the interaction of the natural and the cultural in child development:

> The growing of the normal child into civilization usually represents a single merging with processes of his organic maturation. Both plans of development — the natural and the cultural — coincide and merge. Both orders of changes mutually penetrate each other and form in essence a single order of social-biological formation of the child personality. To the extent that organic development occurs in a cultural environment, to that extent it is turned into a historically conditioned biological process. (Vygotsky, 1987, pp. 19-20)

This natural and cultural past empowers (and also limits) the Subject's Activity. The *natural* past endowed humans with the innate ability to form *internal* representations that are coordinated with the *external* world. This coordination, responsive to veridicality (Carey, 2009, p. 449), and shared with other animals, help our bodies survive in a complex world.

What needs further explanation is the dynamics of representation at the sensory-perceptual or conceptual scales and on how one can develop unto the other. How does the brain create representations? How do distant neuronal assemblies responding to features of an object, pool information together to create a coherent representation? How are these representations retrieved from memory?

4.5.1 Same scale domain coordination – An example of sensory-perceptual Activity

I will now try to illustrate how these representations might develop, departing from the sensory-perceptual domain of Activity as a frame of reference.

Revisiting the concept of direct operations described by Vygotsky in an earlier section, interpreted now as sensory-perceptual Activity, let us imagine an Activity in which the organism (Subject) interacts with an object (Other) towards a goal. This interaction involves not only changes in interoceptive modalities, concerning the organism's interoceptive changes in the trajectory of Activity (Subject-oriented), but also changes in exteroceptive modalities, concerning the organism's exteroceptive changes in the trajectory of Activity (Other-oriented), and changes in proprioceptive modalities, concerning the organism's proprioceptive changes in the trajectory of Activity (Apparatus-oriented).

The model here proposed for sensory-perceptual Activity considers 3 modalities of changes in neural assemblies, represented by signs:

1. Interoceptive signs representing the trajectory of Activity;
2. Exteroceptive signs representing the trajectory of Activity;
3. Proprioceptive signs representing the trajectory of Activity.

The use of the term sign is deliberate, replacing Damásio's use of maps or images (2010), for its philosophical richness and the underlying themes of signification and representation. An important feature of signs is that they are performative, representing changes in these three modalities.

Table 4.3 – Varieties of signs and their source changes in Activity (adapted from Damásio, 2010, p. 64)

	Signs	Changes of neural assemblies
I	Signs of the organism's internal structure and state (interoceptive) in activity	Changes in functional condition of body tissues such as the degree of contraction/distension of smooth musculature; parameters of internal milieu state
P	Signs of the organism's body dispositions (proprioceptive) in activity	Changes of specific body components such as joints, striated musculature, some viscera
E	Signs of the world external to the organism (exteroceptive) in activity	Changes to sensory probes such as the retina, the cochlea, or the mechanoreceptors of the skin

The interaction between the organism and the object involves a Trajectory of simultaneous changes in interoceptive and exteroceptive modalities, with coordination of these two modalities achieved through changes in proprioceptive modalities, in this example at a sensory-perceptual domain. Let us name intermodality, this trajectory of Activity in the same domain, as horizontal and as such, assume that sensory-perceptual Activity enacts a Non-Iterative Programme. An example of this kind of programme is neonates orienting visually to a location specified by a sound (Carey, 2009, p. 39).

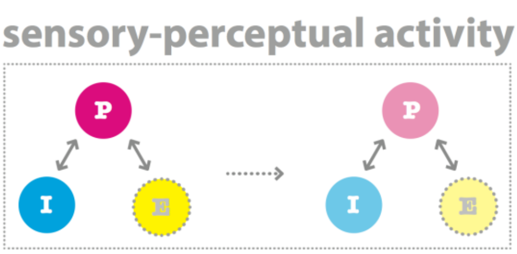


Figure 4.17 – Schema representing the **Trajectory** of changes in interoceptive (I), exteroceptive (E) and proprioceptive (P) modalities in the Subject in a sensory-perceptual Activity

Non-iterative programmes in horizontal Trajectories

A Programme reflects the computational nature of Activity, as a proprioceptive representation of the Activity's Trajectory. Mayr (1992) calls teleonomic to every process that owes its goal-directedness to the operation of a programme:

> All teleonomic behaviour is characterized by two components. It is guided by "a program" and it depends on the existence of some end point, goal, or terminus which is foreseen in the programme which regulates the behavior. This end point might be a structure (in development), physiological function, the attainment of a geographical position (in migration), or a "consummatory act" in behaviour. (p. 127)
>
> A programme might be defined as coded or prearranged information that controls a process (or behavior) leading it towards a goal. The programme contains not only the blueprint of the goal but also the instructions of how to use the information of the blueprint. A programme is not a description of a given situation but a set of instructions. (Mayr, id., p. 128)

In this sense, any Activity is teleonomic as it enacts a **Programme**. Programmes are *written* through natural selection, cultural-historical selection, or individual selection in prior Activity (experience) and are proprioceptive representations of the Activity's trajectory.

The **Goal** is an exteroceptive representation of the Activity's Trajectory.

The **Motive** is an interoceptive representation of the Activity's Trajectory.

4.5.2 Different scale domain coordination – An example of conceptual Activity

In the case of non-iterative programmes, the end state of Activity is on the same domain than the initial state of Activity, following a horizontal trajectory. However, human Activity, as made clear by the work of Carey, considers articulation between conceptual domains besides sensory-perceptual ones, which through sensory-perceptual input analysers, correlate to the organism's interaction with the object.

In the previous example of sensory-perceptual Activity, intermodality (Carey, 2009), or coordination of multiple changes in sensory-perceptual modalities (interoceptive, exteroceptive and proprioceptive), what I called horizontal trajectory, cannot alone explain representations that go beyond the sensory-perceptual vocabulary.

> (…) even once all those intermodal representations are formed, infants still would not have representations that go beyond sensory vocabulary - no representations of individuated, spatio-temporally continuous objects that exist independently of themselves. Second, there is now massive evidence that intermodal representations are innate and certainly not learned through the associative mechanisms Piaget and the empiricists imagined.

> Neonates orient visually to a location specified by a sound; neonates represent the correspondence between visually and tactually specified shapes; and neonates represent the correspondence between visually specified and proprioceptively specified facial gestures. (Carey, 2009, p. 39)

To further explain how a conceptual representation, or what I will now call sign, can form from sensory-perceptual signs, I will need to elaborate on the concept of **Scale**, describing a vertical trajectory of Activity (a change to an upper scale domain) using prior sensory-perceptual signs as subsumers (Ausubel, 2003).

I will start with the claim that the previously described sensory-perceptual Activity can become one of several subsumers (Ausubel, 2003), through an iterative Programme, for an upper conceptual Activity scale domain. This claim will be supported by elaborating on Damásio's model of image and dispositional spaces in the brain and convergence-divergence zones (2010, Meyer & Damásio, 2009), Barsalou's model of situated conceptualisations (2009) and Fingelkurts and colleagues model of Operational architectonics (2005, 2013).

The neural architecture of the human brain proposed by Damásio is constituted by two main elements, the image space and the dispositional space. The changes in neuron assemblies in the image space during the interaction of the organism with an object create signs (maps/images in Damásio's account) from all sensory modalities:

> The image space is located in the map-making brain, the large territory formed by the aggregate of all the early sensory cortices, the regions of cerebral cortex located in and around the entry point of visual, auditory, and other sensory signals into the brain. It also includes the territories of the nucleus *tractus solitarius*, parabrachial nucleus, and superior colliculi, which have image-making capability. (Damásio, 2010, p. 112)

The neuron assemblies in the dispositional space operate as convergence-divergence zones (CDZ), receiving convergent projections from the early sensory assemblies in multiple modalities.

> CDZs contain records of the combinatorial arrangement of the knowledge fragments coded in the early cortices, that is, they hold information about how those fragments must be combined to represent an object comprehensively. CDZ records are shaped by experience. When the organism interacts with an object, several aspects of the interaction are mapped simultaneously at separate sites in early sensorimotor cortices. The temporally coincident activity at the separate sites modifies the connectivity patterns to, from and within a shared CDZ downstream, with the result that the various fragments of information about the object become associated. The convergent–divergent connectivity principle exists at all levels of the processing hierarchy: just as first-order CDZs inscribe records of the combinatorial arrangement of knowledge fragments in early cortices, second-order CDZs inscribe records of the combinatorial arrangement of first-order CDZs, and so forth. (Meyer & Damásio, 2009, pp. 376-377)

As a practical example, a schema representing a convergent–divergent activation cascade upon seeing a lip movement is presented next.

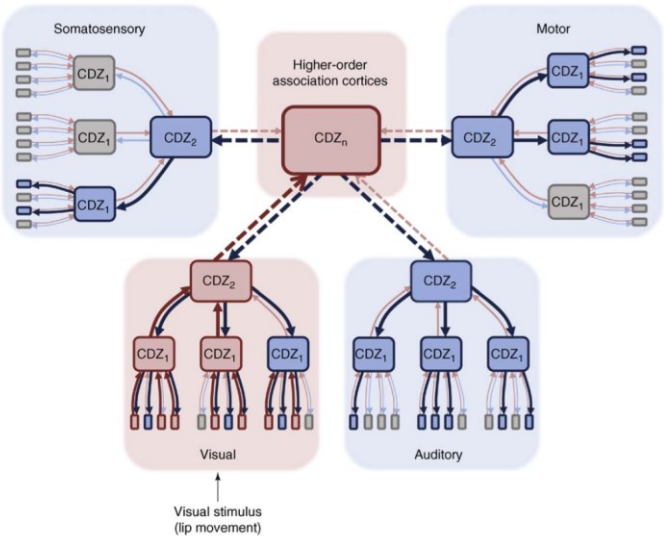


Figure 4.18 - Convergent–divergent activation cascade upon seeing a lip movement. Visual apprehension of a lip movement elicits a specific activity pattern in early visual cortices (red rectangles). The two CDZ1s on the left (red) are activated by this activity pattern via convergent forward projections (bold red arrows); the CDZ1 on the right is not. In this case, the specific activation pattern of CDZ1s activates the CDZ2 and the CDZn in higher-order association cortices (via several steps not represented here). The CDZn sends divergent back projections (bold blue arrows) to CDZ2s in various sensorimotor areas (including the one in the visual sector that has promoted the forward activation cascade). Via further retro-activation of CDZ1s, the retro-activated CDZ2s reconstruct, in early cortical sectors, the activity patterns previously associated with the observed lip movement, for example the sound typically associated with it in addition to its motor or somatosensory representations (blue rectangles). Red designates areas activated by forward projections whereas blue denotes retro-activated areas. Note that the initial visual representation of the stimulus (both at the level of the CDZ1s and at the level of early cortical sectors) may be rendered more complete by means of retro-activation (parts of the visual sector colored in blue). (Meyer & Damasio, 2009, p. 379)

The dispositional space, or the Apparatus in the terminology that I am using, does not hold the meaning of objects and events themselves but, rather, establishes meaning via time-locked multiregional retroactivation of early cortices (Meyer & Damásio, 2009). The dispositional space holds know-how, that is, a Programme that affects the vertical Trajectory of, in this example, sensory-perceptual Activity to conceptual Activity. As such, it can potentially generate, through a signification process, a sign of signs.

Iterative programmes in vertical Trajectories

Using the process proposed by Damásio, sensory-perceptual, temporally coincident Activity in the early image space modifies the connectivity patterns to, from and within a shared first-order dispositional space or CDZ, constituting a subsumer, together with other structurally similar subsumers, that are coordinated through a second-order CDZ. I present next a schema that can resume this process.

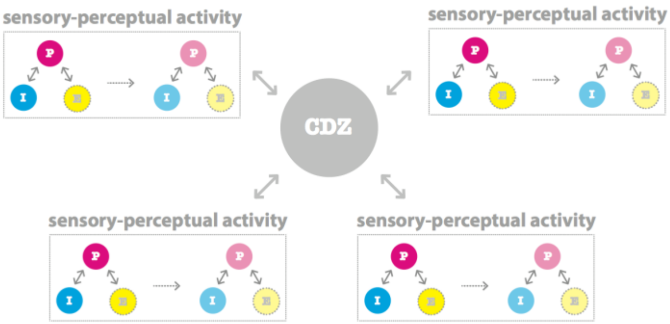


Figure 4.19 – The activity of a first-order CDZ, in sensory-perceptual Activity, coordinates with the activity of the image space, with its interoceptive (I), proprioceptive (P) and exteroceptive (E) modalities

This process can occur again, with second-order CDZs, coordinating with the activity of first-order CDZs, in sensory-perceptual Activity:

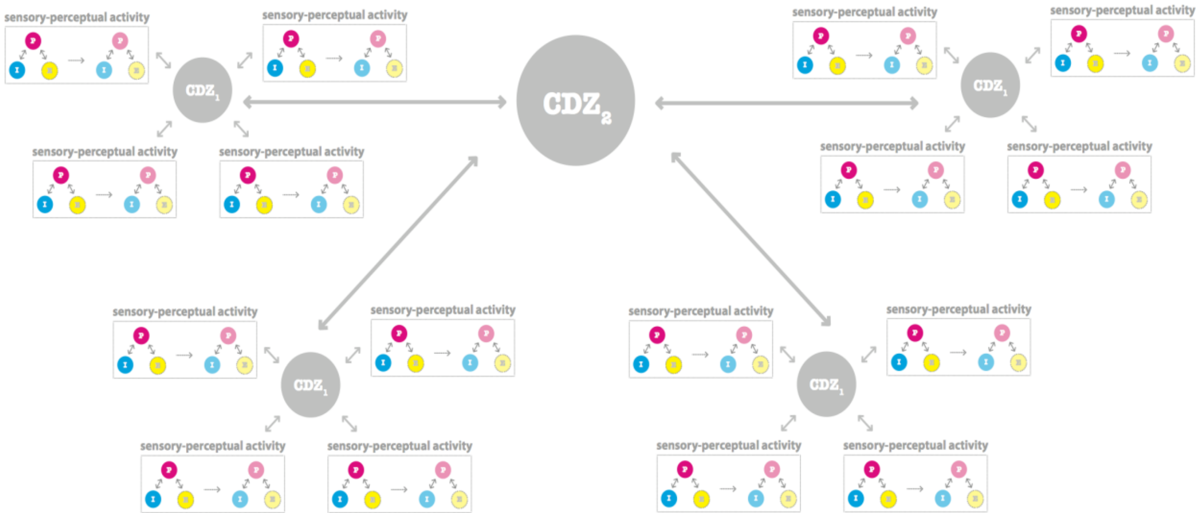


Figure 4.20 – A second-order CDZ (centre), coordinates with multiple first-order CDZs, in sensory-perceptual activity.

The critical element in Damasio's framework, manifest in the above schemas, is the separation of these two kinds of brain systems, one responsible for making signs (maps/images in the author's account) and other for making dispositions – the image space and the dispositional space, respectively.

My proposal is that these CDZs are not inherently dispositional, and act also as *image* spaces *for higher-order* CDZs, being self-similar with sensory-perceptual Activity and representing changes in *lower-order* intero-, extero- and proprio- modalities, depending on the scale domain of Activity.

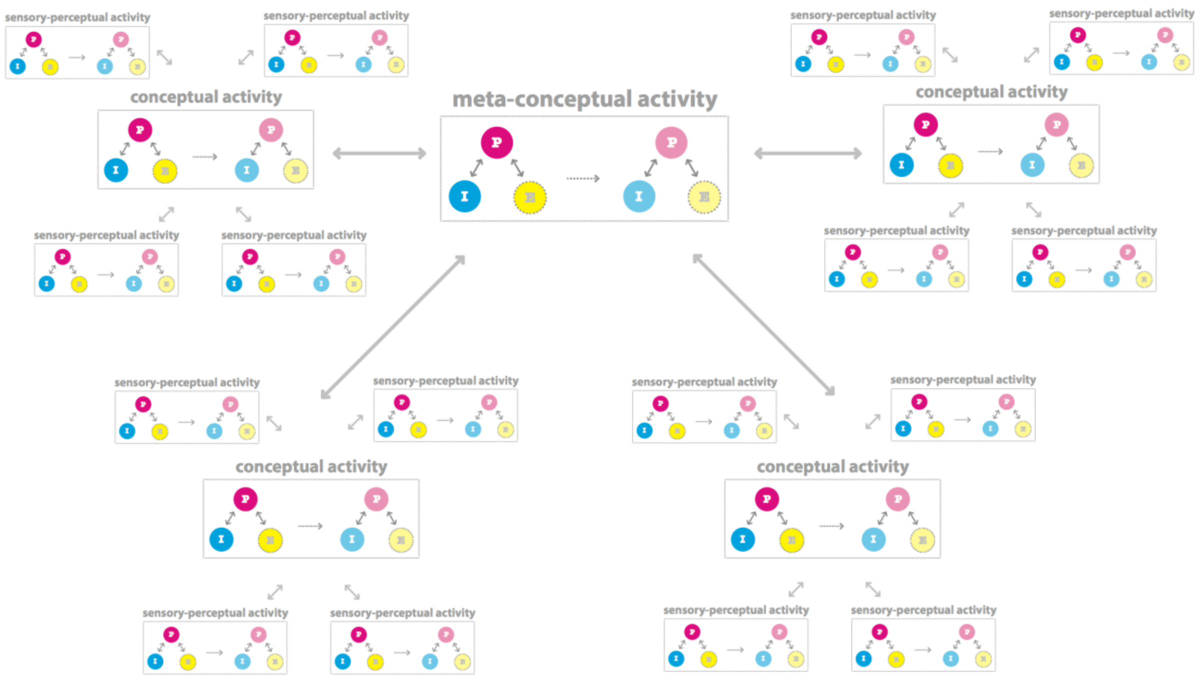


Figure 4.21- Sensory-perceptual activity as a subsumer for conceptual activity, which in turn acts as a subsumer for meta-conceptual activity

This convergence (integration) and divergence (differentiation) mechanism allows not only a convergent trajectory, that is, creation of meta-conceptual Activity from conceptual and sensory-perceptual Activity but also a divergent trajectory, that is, the creation of sensory-perceptual Activity from conceptual and meta-conceptual Activity. Human Activity in this sense can begin in any scale domain, engaging the remaining domains through convergence-divergence.

To represent the idea that this model is self-similar, a new schema is presented next, reflecting the view that the dispositional space can also act as image space for interoceptive, exteroceptive or proprioceptive modalities in every scale domain:

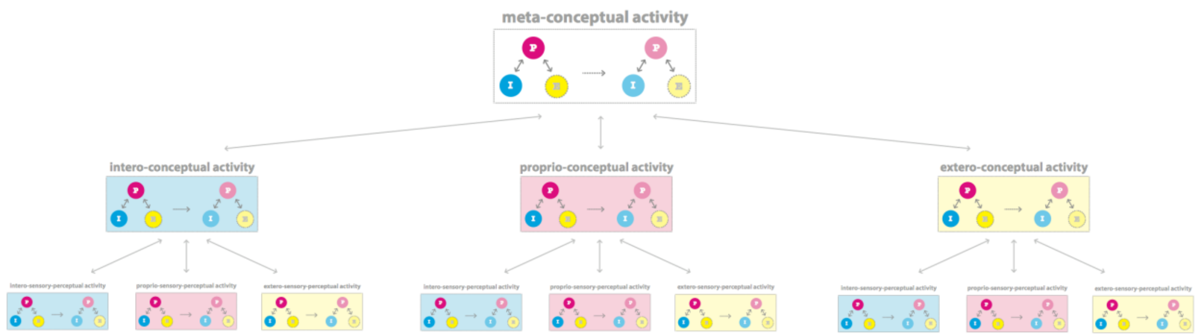


Figure 4.22 – Meta-conceptual activity requires multiple conceptual activities which in turn require multiple sensory-perceptual activities. Notice the maintenance of the three modalities at all scale domains, intero-, proprio- and extero-

This model is consistent with:

1. Damasio's (2010) mechanism of CDZs and notions of proto-self, core self, autobiographical self, as intero-signs in the multiple scale domains (intero-sensory-perceptual, intero-conceptual and intero-meta-conceptual);
2. Barsalou's model of situated conceptualisations, in which cognition and memory are performative, re-enacting modal states that support goal achievement in specific contexts. The brain can be viewed as a coordinated system that generates a continuous stream of multi-modal predictions during situated action:

> According to traditional views, bicycle is represented as a generic set of amodal propositions that become active as a whole every time the category is processed. According to the view proposed here, however, the cognitive system produces many different situated conceptualizations of bicycle, each tailored to help an agent interact with bicycles in different situations. For example, one situated conceptualization for bicycle might support riding a bicycle, whereas others might support locking a bicycle, repairing a bicycle and so forth. On this view, the concept for bicycle is not a single generic representation of the category. Instead, the concept is the skill or ability to produce a wide variety of situated conceptualizations that support goal achievement in specific contexts. (Barsalou, 2009, 1238)
>
> Once situated conceptualizations become entrenched in memory, they support a pattern completion inference process (Barsalou 2003b; Barsalou et al., 2003). On encountering a familiar situation, an entrenched situated conceptualization for the situation becomes active. Typically, though only part of the situation is perceived initially. A relevant person, setting, event or introspection may be perceived, which then predicts that a particular situation - represented by a situated conceptualization—is about to unfold. By running the situated conceptualization as a simulation, the perceiver anticipates what will happen next, thereby performing effectively in the situation. The agent draws inferences from the simulation that go beyond the information given. (Barsalou, 2009, p. 1284)

3. Fingelkurts and colleagues' model of Operational architectonics, in which every simpler cognitive operation exists within a more complex one, in a metastable regime of brain functioning.

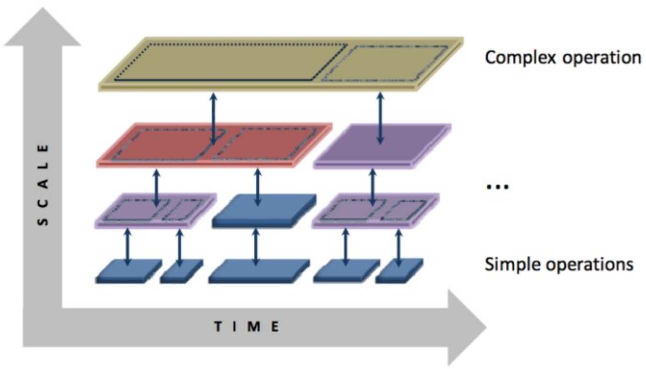


Figure 4.23 - Schematic representation of the compositionality of operations (Fingelkurts et al., 2013, p. 12)

(…) "operation" formally stands for a process (or series of acts/functions) that applied to an operand, yielding a transform, and which is limited in time (it has a beginning and an end). In broad terms, it can be defined as the state of being in effect. This definition provides a basis for discussing the relative complexity and compositionality of operations, where there is a more complex operation/operational act that subsumes the simpler ones. In other words, each operation of this nested hierarchy of operations is not monolithic, – instead it has its own inherent fine structure: every simpler operation exists within every other more complex one. Therefore, operations should not be considered as objects in a conventional sense. Rather, they should be seen as reciprocally entangled "autopoietic machines", i.e., self-creating processes, or dissipative structures that are nevertheless relatively stable and thus, only in that sense, could be conceived as distinct "objects". (Fingelkurts et al., 2013, p. 12)

Indeed, as it is shown in the recent review by Bressler, the cortex dynamically generates global neuro-cognitive states from interactions among its areas using local and remote patterning within the cortex, whereas each cortical area is a relatively autonomous entity and has a unique pattern of interconnectivity with other cortical areas. These considerations suggest that brain integrative functions are the result of competition of complementary tendencies of cooperative integration and autonomous fragmentation among many distributed areas. The interplay of these two tendencies (autonomy and integration) constitutes the metastable regime of brain functioning, whereas local (autonomous) and global (integrated) processes coexist as a complementary pair, not as conflicting principles. (Fingelkurts et al, 2009, p. 2)

In the following table are represented some vertical trajectories of human Activity, either scaling up or scaling down.

Table 4.4 – Vertical trajectories of human Activity

Vertical trajectory ↑	**Low-order sign**	**Signification process**	**High-order sign**
Sensory-Perceptual → Conceptual	Sensations-Percepts	Conceptualization	Concept (sign of signs)
Conceptual → Meta-conceptual	Concepts	Meta-conceptualization	Meta-concept (Sign of signs of signs)
Vertical trajectory ↓	High-order sign	Signification process	Low-order sign
Meta-conceptual → Conceptual	Meta-concept	Conceptualization	Concepts
Conceptual → Sensory-Perceptual	Concept	Sensation-Perception	Sensations-Percepts

4.6 A framework to analyse Activities in the Science Learning Studio

I will now try to systematise the main ideas developed in the previous sections, departing from a schema:

Figure 4.24 – A schema for human Activity

Some of the main differences to SSAT schema are the following:

- Subject-Object and Subject-Subject varieties of interaction are replaced by **Subject-Other** interaction as a more abstract concept that includes human and non-human others;
- Tools/Signs are replaced by **Apparatus** as a more abstract concept and are mandatory to mediate the relationship between Subject and Other. Direct operations in Vygotsky's sense are also mediated operations. The same applies to the use of instruments and to the use of signs (sensations-percepts, concepts, meta-concepts);
- The result of Activity is represented as an end state of the initial state, following a **Trajectory**;
- The **Motive**, **Programme** and **Goal** are multimodal representations of the Activity's Trajectory – interoceptive, proprioceptive and exteroceptive respectively;
- The **Units of analysis** depend on the defined referential Activity. A task, for example, can be analysed as Activity or action depending on the framing of the analysis.

The proposed definitions for the main terms are the following:

Table 4.5 – Terms and definitions in my account of Activity Theory

Term	Definition
Activity	The main object of study, is represented by a Trajectory from an initial to an end state. Can be subdivided into tasks, which are subdivided into actions, and later in operations.
Subject	The defined reference individual performing the Activity.
Other	That which is modified by a Subject (and modifies the Subject in the process) in Activity. Can be human or non-human, concrete or abstract, depending on the scale of Activity (sensory-perceptual, conceptual, meta-conceptual).
Apparatus	Mediators between the Subject and the Other, can be human or non-human, concrete or abstract, depending on the scale of Activity.
Scale domain	For example, sensory-perceptual, conceptual, meta-conceptual, etc. Higher domain Activity always requires lower domain Activity, but the opposite is not necessarily so.
Motive	Interoceptive representation of the Activity's Trajectory.

Term	Definition
Programme	Proprioceptive representation of the Activity's Trajectory.
Goal	Exteroceptive representation of the Activity's Trajectory.

Millar's approach (2010) to practical activities analysis emphasises the linking of the domain of objects and observables to the domain of ideas as the main purpose of practical work. In the activity analysis methodology here presented, this general idea stands as the same, not only for practical work but for other Science lessons' patterns. The domain of objects and observables is interpreted as sensory-perceptual in this account, and the domain of ideas is interpreted as conceptual and meta-conceptual. The linking between all of these domains through the creation of percepts, concepts and meta-concepts by iterative and non-iterative programmes is then one of the main purposes of learning activities in the Science Learning Studio more broadly.

As previously stated, one critical element in this analysis methodology is the production of Pedagogical Graphical Novels, as a form of documentation of a Science Learning Activity, with a certain degree of sensory-perceptual fidelity to the *live* Activity. However, an analysis methodology is still required.

Departing from the previous schema and definitions, the main methodology proposed for the analysis of a learning Activity is presented in the following table.

Table 4.6 – The SLS Activity Analysis Methodology

Step	Method	Description
1	**Define and decompose the units of analysis**	Activity can be analysed depending on the unit of analysis, such as task, action or operation. For daily teachers' use, the task and action levels should be enough to provide opportunities for reflection.
2	**Define the leading scale domain for each unit of analysis and the transitions between domains**	Every task in a learning activity can be positioned in a scale domain (sensory-perceptual, conceptual, meta-conceptual), with some tasks concerned with the transition between scale domains.
3	**Analyse the goals for each unit of analysis**	Every task in a learning activity has a goal or set of goals and should be coordinated with both the motives and the programme.
4	**Analyse the motives for each unit of analysis**	Every task in a learning activity has a motive or set of motives and should be coordinated with both the goals and the programme.
5	**Analyse the programme for each unit of analysis**	Every task in a learning activity has a programme and should be coordinated with both the goals and the motives.

4.6.1 Units of analysis

The units of analysis are established depending on the defined reference Activity. Considering as learning Activity the determination of the density of metals using a pycnometer, the tasks are for example: 1) Planning of the practical work; 2) Practical work; 3) Data analysis and 4) Discussion. If the activity in the analysis is only practical work, then tasks might include 1) Gathering and organising the required equipment and materials; 2) Measuring the mass of the empty pycnometer; 3) Measuring the mass of the pycnometer full of distilled water, etc.

The hierarchy of units of analysis departs from the Activity itself, which can be divided into tasks, tasks into actions and actions into operations.

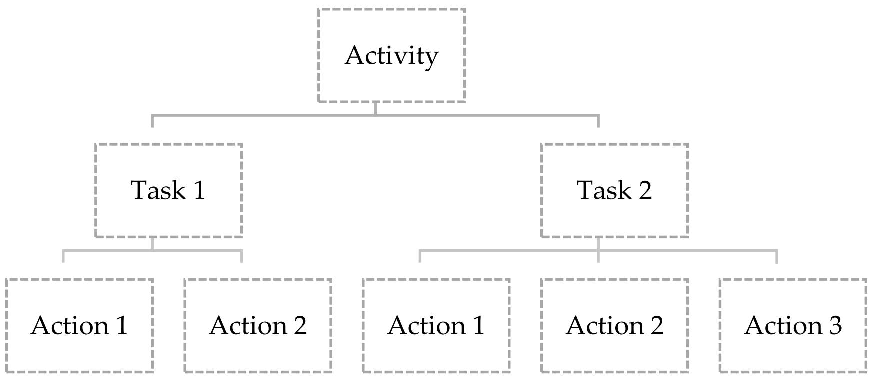


Figure 4.25 – An example of units of analysis of Activity

4.6.2 Scale domains and goals

The scale domains proposed, as a heuristic useful for practice (of more complex taxonomies that can be informed by the fields of Neurosciences and Conceptual Change), can be useful to the analysis in a Science Education context:

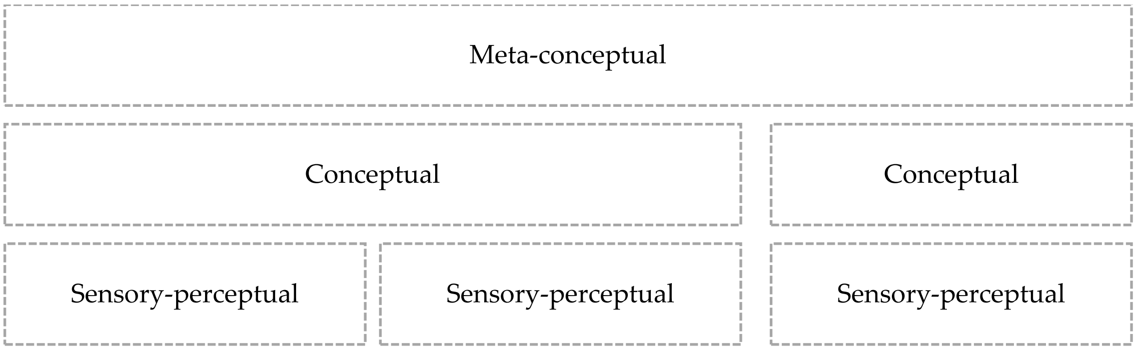


Figure 4.26 – Scale domains of Activity

The scale domains of Activity can be helpful to categorise learning goals and decide on both motivational strategies and the required programme for the learning activity. Some examples from Science Education related goals are presented in the following list, organised by scale domains:

1. **Sensory-perceptual**, related to learning:
   - To use a piece of equipment, tool or software;
   - To observe an aspect or property of an object, natural event or entity;
   - To measure a quantity;
   - To make an object;
   - To follow a procedure with observables.
2. **Conceptual**, related to learning:
   - Concepts, explanatory ideas, models, theories and their relationships;
   - To report observations using scientific terminology;
   - To identify a similarity or difference (between objects, or materials, or events);
   - The effect on an outcome of a specific change (e.g., of using a different object, or material, or procedure);
   - How an outcome variable changes with time;
   - How an outcome variable changes when the value of a continuous input variable changes;
   - How an outcome variable changes when each of two (or more) input variables changes;
   - To obtain a value of a derived quantity (i.e. one that cannot be directly measured);
   - To make and/or test a prediction;
   - To decide if a given explanation applies to the particular situation observed;
   - To decide which of two (or more) given explanations best fits the data;
   - To suggest a possible explanation for data.
3. **Meta-conceptual**, related to learning epistemic aspects of the scientific approach to enquiry:

- Identify a good investigation question;
- Plan a strategy to measure, collect data or observe to address a question;
- Choose equipment for an investigation;
- How to present data clearly;
- How to analyse data to reveal or display patterns;
- How to draw and present conclusions based on evidence;
- How to assess how confident can we be in a conclusion (adapted from Millar, 2009).

Authentic learning goals – going beyond canonical Science Education goals

The Greek origin of the word authentic, αυθεντικός and authentēs, refers both to "conforming to an original so as to reproduce essential features", "not false or imitation", "genuine" as to "perpetrator, master", "true to one's own personality, spirit, or character", "authoritative" (Oxford Dictionaries, 2006).

At least two views are in place in this definition of authentic. The first is about conformity to the original, in this case, Science. The second is about the conformity to one's identity, in the case of school Science, students and teachers:

> (…) authentic Science experiences are those in which participants are provided the opportunity to participate through actions that entail changes in these practices and therewith produce and reproduce this practice rather than only observe them. Most importantly, authenticity involves control, authorship, and mastery. (Roth et al., 2008, p. 197)

In a model of scientific inquiry based on scientists' motivations, scientific inquiry skills and research results as the image towards which school Science inquiry should aim, teachers and students control, authorship and mastery are not accounted for, in a kind of fetishism towards school Science.

Roberts (2007) in his chapter Scientific literacy/Science literacy in the Handbook of Research on Science Education distinguishes between two visions that underlie different conceptions of scientific literacy: Vision I "gives meaning to SL [scientific literacy] by looking inward at the canon of orthodox natural Science, that is, the products and processes of Science itself. " (p. 730).

However, for a Science education for all, not just future scientists, Vision II should also be present from the onset, a vision which "derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens. At the extreme, this vision can be called literacy (again, read through knowledgeability) about Science-related situations in which considerations other than Science have an important place at the table" (Roberts, 2007, p. 730).

On this Vision II, Roth and Barton (2004) clarify its authenticity from the point of view of students and teachers:

> For many Science educators, efforts to promote greater scientific literacy have been shaped by the image of laboratory Science. (...) we intend to shift the discourse about Science and scientific literacy by considering three (radical?) propositions. First, we propose that scientific literacy is a property of collective situations and characterizes interactions irreducible to characteristics of individuals. Second, we propose to think of Science not as a single normative framework for rationality but merely as one of many resources that people can draw on in everyday collective decision-making processes. Third, we propose that people learn by participating in activities that are meaningful because they serve general (common) interests and, in this, contribute to the community at large rather than making learning a goal of its own. (p. 22)

School Science is part of the core curriculum in Portugal for over a century. Its main goal is not to prepare scientists or Science teachers but to help create informed citizens as well as introducing children to the language, purposes, impact and limitations of Science. Humanistic Science education learning outcomes include in practice (Aikenhead, 2006):

> "(1) to make the human aspects of western Science more accessible and relevant to students; (2) to help students become better critical thinkers, creative problem solvers, and especially better decision makers in their everyday lives related to western Science and technology; (3) to increase students' capabilities to communicate with scientific and technological communities or media spokespersons; (4) to augment students' commitment to social responsibility (citizenship); and (5) to increase interest and achievement in learning canonical knowledge found in the traditional curriculum or in other sources of western scientific knowledge". (p. 84)

Hodson expands this idea in an interesting way:

> What else should be regarded as crucial to a claim of being scientifically literate? Understanding the nature of Science? Understanding the major theoretical frameworks of biology, chemistry and physics? Understanding the complex relationships among Science, technology, society and environment? Knowing about the historical development of the 'big ideas' of Science and the circumstances that led to the development of key technologies? Being aware of contemporary applications of Science? Having the ability to use Science in everyday problem solving? Holding a personal view on controversial issues that have a Science and/or technology dimension? Possessing a basic understanding of global environmental issues? (Hodson, 2002, p. 4)

Following the suggestion by Dillon (2009) that we should think about multiple scientific literacies, in both curriculum reform and development, and that the conceptualisation of what it means to be scientifically literate can be read as a meta-level set of goals, I would like to propose multiple goals that could be considered as a representation of a richer Science Education, authentic not only in the perspective of Science, but also of students and teachers alike:

- Personal and family goals (educating children, improving family life, exchanging interpretations of the world, scientific views and culture, solving everyday problems, pursuing healthy lives, farming own food and cooking, critically reading books, critically watching TV and other media, choosing lunch, ethically and critically buying commodities, dealing with personal finances, pursuing hobbies and sports, …);

- Closer social group goals (helping a friend solve everyday problems, exchanging interpretations of the world, scientific views and culture, having rich conversations about actual needs or future aspirations, engage in collective entertainment activities, prepare for elderly age, …);
- Education and training goals (integrating multiple academic subjects' knowledge, developing interdisciplinary projects, intervene in school matters and improve school life, …);
- Professional goals, Science related or not (personally, socially, technically, academically, participate in professional bodies, labour organisations, …);
- Local, regional, national and trans-national citizenship goals (helping improve community life and the environment, volunteering, participating in collective community projects, from citizen Science to a more institutional level, giving educated opinions in blogs and other media, dealing with the micro and macro issues of living together).

This demands not only curriculum development (and reform) processes that identify the intersections of more canonical Science curriculum goals with these multiple goals, but also the design of learning activities that are authentic from all these standpoints.

4.6.3 Motives

Self-Determination Theory (SDT) is a broad framework for the study of human motivation and personality, developed initially by Deci and Ryan and later improved by several scholars. One of the main arguments of this theory is that conditions that support the individual's basic psychological needs for autonomy, competence and relatedness affect outcomes such as high-quality forms of motivation, engagement, personality growth, well-being, quality of experience, enhanced performance, persistence, resilience and creativity.

Briefly stated, 1) Autonomy refers to the experience of volition, integrity, and vitality that accompanies self-organised and self-regulated action; 2) Competence refers to the experience of effectiveness in interacting with one's environment; 3) Relatedness concerns the experience to cohere with one's group, to feel connection and caring, to internalize group needs and values in order to coordinate with others (Deci & Ryan, 2000).

When basic psychological needs are fulfilled, the subject is self-determined. However, human behaviour is not exclusively self-determined. Whenever a teacher proposes an activity to students, their motivation for the behaviour can range from non-intentional, to passive compliance, to active personal commitment. According to SDT, these different motivations reflect different degrees to which the value and regulation of the requested behaviour have been internalised and integrated. Internalisation refers to the subject's *taking in* a value or regulation, and integration refers to the further transformation of that regulation into their own so that, subsequently, it will emanate from their sense of self (Ryan & Deci, 2000, p. 71).

Besides intrinsic motivation, amotivation and four types of extrinsic motivation are described by Deci and Ryan (2000), located on a self-determination continuum. Amotivation is at the lower end of the continuum, corresponding to non-regulation. External regulation means doing something in order to comply, to gain external rewards or avoid external punishment. Introjected regulation means doing something with ego-involvement, to gain feelings of control (internal rewards) or avoid feelings of guilt (internal punishments). Identified Regulation means doing something that is perceived as personally important. Integrated regulation means doing something coherent with the subject's other values, personality and sense of self. Finally, intrinsic motivation is an inherent tendency to do something to seek out novelty and challenges, to extend and exercise one's capacities, to explore, and to learn, a full manifestation of self-determined behaviour.

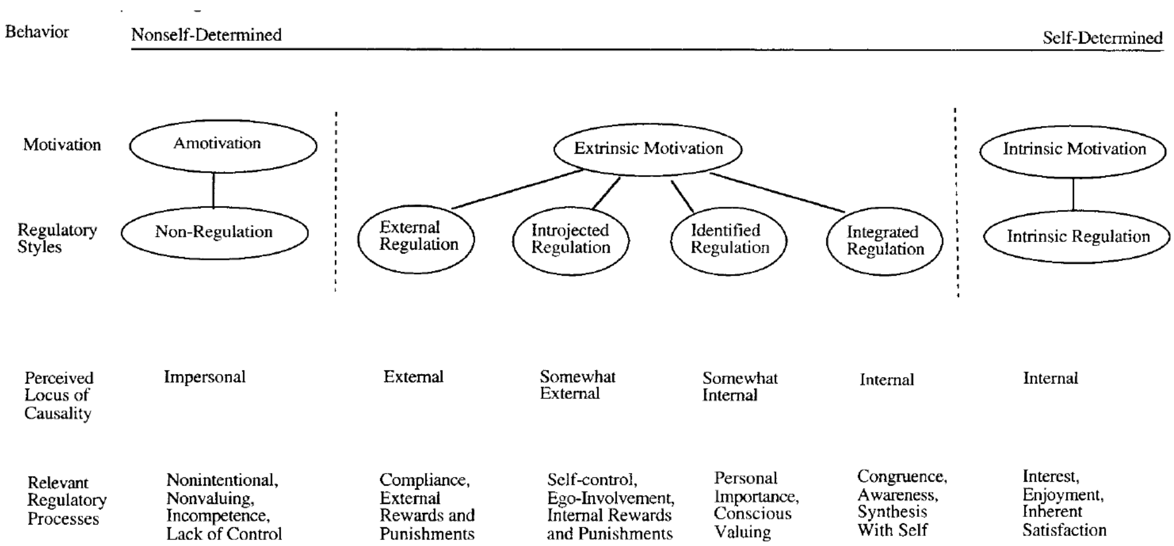


Figure 4.27 – Self-determination continuum, types of motivation, regulatory styles, perceived loci of causality and relevant regulatory processes (Ryan & Deci, 2000, p. 72)

4.6.4 Programmes

As previously mentioned, two kinds of programmes can be considered in a learning Activity – non-iterative and iterative. The former takes place in the same scale domain (sensory-perceptual, conceptual or meta-conceptual). In the case of an iterative programme, transition between domains is required.

Does the activity begin by collecting data as observations and measurements? Or does it begin from thinking about a situation or question, predicting outcomes, and then collecting data to see if the prediction is correct or must be modified? Or does it begin by defining the research problem in the first place? The first situation has its risks, as Millar (2009) stated:

> (…) there is a risk that activities that begin from data may be based on what Driver (1983) called 'the fallacy of induction', that is, the idea that explanations 'emerge' from observations. This significantly underestimates the challenge for learners. An explanation may be obvious to the teacher, who already knows it, but not at all obvious to a student. If much practical work is ineffective for developing students' understanding of ideas and explanations, as research seems to suggest, then part of the reason may lie in the logical structure of the practical activities we use. So it is useful to reflect on this aspect of design – particularly for activities that aim to develop understanding of explanatory ideas. (p. 11)

Activities in the Science Learning Studio should emphasise iterative learning programmes linking multiple domains of signification. Tangibles, ponderables and open inquiry activities are iconic forms of activities that can afford these iterative programs.

Tangible activities are usually short tasks related to physical situations, where students must gather data, and make hands-on measurements or observations. Ponderables similarly require estimating or finding values from other sources, with no observation or measurements required.

Open inquiry activities give a central importance to the individual and its mediating role in defining meaning, establishing learning needs, determining learning goals, and engaging in learning activities (Hannafin et al., 1999, p. 119).

Open inquiry activities can be particularly useful to promote divergent thinking and in situations where a diversity of perspectives is valued, as in an issues-based approach proposed by Hodson (2008, p. 4). These also "promote the discovery and manipulation of underlying beliefs and structures rather than impose beliefs, support students' autonomy as they encourage individuals to generate problems and needs, select among various available information sources, and evaluate their judgments" (Hannafin et al., 1999, p. 120).

Table 4.7 – Distinction between directed learning activities and open inquiry activities (adapted from Hannafin et al., 1999, p. 119)

Directed learning activities	**Open inquiry activities**
Break down content hierarchically and teach incrementally toward externally generated objectives	Situate processes associated with problems, contexts, and content with opportunities to manipulate, interpret and experiment
Simplify detection and mastery of key concepts by isolating and instructing to-be-learned knowledge and skill; "bottom-up", basics first	Employ complex, meaningful problems that link content and concepts to everyday experience where "need to know" is naturally generated
Convey knowledge and skills through structured, engineered teaching-learning approaches	Centre heuristic approaches around "wholes" exploring higher order concepts, flexible understanding and multiple perspectives
Mediate learning externally via explicit activities and practice; promote canonical understanding as a goal	Develop understanding individually as learners evaluate their own needs, make decisions and modify, test and revise their knowledge
Activate internal conditions of learning by carefully engineering external conditions	Link cognition and context inextricably
Achieve mastery by focusing on production of "correct" responses, thereby reducing or eliminating errors	Stress the importance of errors in establishing models of understanding; deep understanding evolves from initial, often flawed beliefs

In this kind of Activity, an *a priori* definition of a teaching curriculum is not applicable. Students and teachers are given autonomy and flexibility to construct this curriculum, both taught and learned. Assessment, in this case, has also to be decided upon, by teachers, students, or a combination of both. Much like in the Design Studio or in the Reggio Emilia Atelier.

4.6.5 A tentative model for curriculum development in the Science Learning Studio

In the context of Science Education, one of the roles of the teacher is to design learning Activities, in which the reference Subject is the student. I share with Driver & Oldham (1986) the notion of the curriculum as a programme of activities from which knowledge or skills can be constructed, as much as their view that curriculum development necessarily requires an empirical reflexive approach:

> By accepting that the curriculum is the programme of activities from which knowledge or skills can possibly be constructed and acknowledging that what is constructed by any individual depends to some extent on what they bring to the situation, in the last analysis the suitability and effectiveness of selected learning activities is an empirical problem. We only sense whether individuals are making sense of the experiences they are given 'in situ'. For this reason curriculum development from a constructivist perspective has to incorporate an empirical reflexive approach. (p. 112)

Driver and Oldham constructivist model for curriculum development considers the following four inputs: 1) decisions on content; 2) information about students' prior ideas; 3) perspectives on the learning process; 4) teachers' practical knowledge of students, schools and classrooms.

> The first and most conventional one is the decision on 'content'. Here we can specify those experiences which students should be exposed to and we can suggest what ideas they may construct on these experiences but we cannot be tightly prescriptive about the ideas they will acquire. If we adopt a view of learning as conceptual change in its broadest sense then we need to have information about the ideas that students may bring to the learning situation. This is the second type of input shown in the figure. (…) a perspective on the learning process (…) guiding the selection of activities. (…) practical knowledge of students in school and classroom settings: how to organise a group of about 30 people to do something in about one hour; how to present a problem to be of interest to a group of 14-year-olds; how to deal with the usual constraints of time, resources, furniture, space. (Driver & Oldham, 1986, pp. 112-114)

These inputs inform the curriculum design, on both learning strategies and materials, later implemented in classrooms, followed by an evaluation of learning, intrinsic and extrinsic.

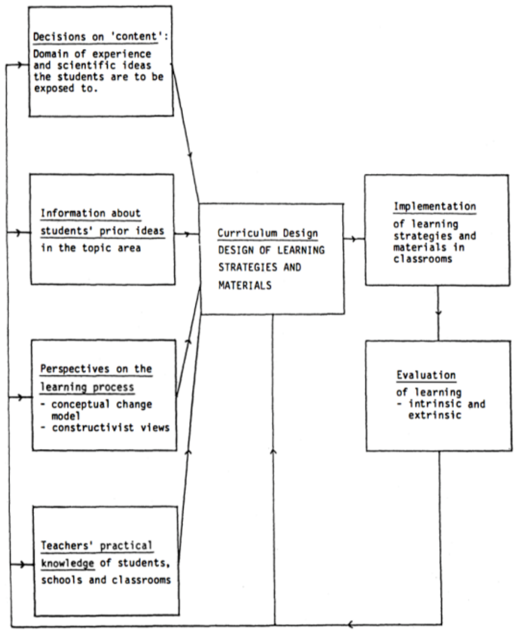


Figure 4.28 - Constructivist model for curriculum development (Driver & Oldham, 1986, p. 113)

My general model for curriculum development considers the framework developed in the previous section, organised into the following elements:

1. **Define learning goals in scale domains** and define how its achievement will be monitored;
2. **Predict students' motives** related to the activity and plan strategies to address non-intrinsic motivation;

3. **Define the learning programme**, how it is presented to students and the transitions between scale domains;
4. **Implement and document** activity;
5. **Reflect** on documented activity.

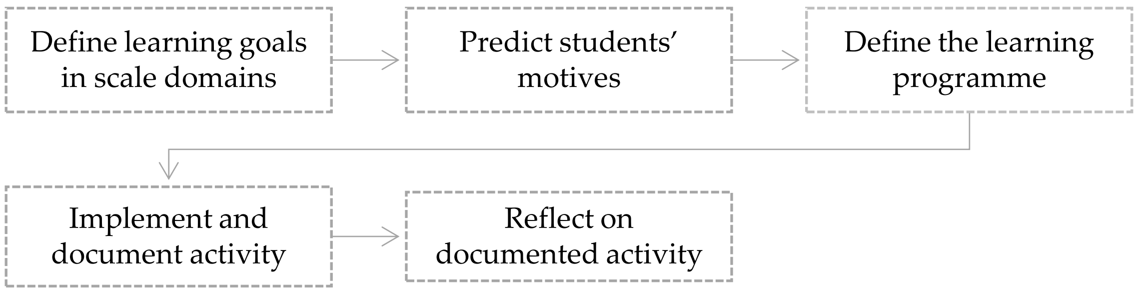


Figure 4.29 – Schema of the curriculum development model

In the following table I present some cues for reflecting and deciding the several elements of the model.

Table 4.8 – Elements of the model for curriculum development and cues for reflection and decision-making

	Element of the model	Cues for reflection and decision making
1	**Define learning goals in scale domains and define how its achievement will be monitored**	How is canonical scientific literacy coordinated with multiple scientific literacies? Position the goals in sensory-perceptual, conceptual and meta-conceptual domains Make clear the goals to students What are students' prior knowledge and experiences related to the learning goals? What instruments are adequate to measure achievement of learning goals across scales? What outcomes will be produced by students that can be used for monitoring practice of both students and teacher? Consider the activity prior to the main activity and assess its relation to the learning goals Consider how the activity leads to the next activity
2	**Predict students' motives related to the activity and plan strategies to address non-intrinsic motivation**	Plan engagement of positive feelings related to the activity (e.g., engage prior positive experiences, use daily observables or engaging products from the activity, elicit applications of concepts to everyday life and student's interests, provide positive feedback) What is the expected autonomy of the student in the activity? For example, will they follow a recipe for practical activity or be autonomous in designing an experiment that they chose? What is the expected competence of the student during the activity? How are relatedness needs addressed in the activity? (Involvement of significant others, student-teacher relationship, student-student, …) What were scientists' motives related to the activity in the History of Science and Technology that can affect student's motives?

	Element of the model	Cues for reflection and decision making
4	**Define the learning programme, how it is presented to students and the transitions between scale domains**	According to the learning goals, students' motives and resources at hand, is an iterative or non-iterative programme more adequate? How will students' prior knowledge and experiences be elicited? Through verbalisation, schematic drawing, role play, simulation, video or pictures presentation and discussion? Resort to both pedagogical knowledge and pedagogical content knowledge to support students in the learning programme (peer instruction, reciprocal teaching, active reception learning, verbalisation through productive talk moves, group work) Decide and organise the resources required to fulfil the programme Engage multiple body dispositions, (e.g., request students to go the whiteboard, express a quantity or procedure with the body and tools, or balance, vibration, reading of texts out loud, schematic drawing and writing, concept mapping, graphic organisers, frayer model, cornell notes, v gowin, argument lines, 4 corners) Engage multiple exteroceptive modalities (e.g., sight, hearing, touch, smell, taste) Provide explicit links from the sensory-perceptual to the conceptual domain (e.g., use observational data to support concept formation, tangible and ponderable activities, photos and videos of students' observable activity, ask students to make estimates with objects) Reify, provide explicit links and scaffold in transitions from conceptual to meta-conceptual domains (e.g., use conceptual "data" to support meta-concept formation, ask students to generate hypothesis, connect to contexts of discovery in history of Science and ideas) Predict concept and meta-concept formation related to the development stage of students and research on conceptual change, related difficulties and misconceptions Make clear the programme of activity to students (e.g., advanced organisers, diagrams, quick or interactive demonstrations, ask students to verbalise or schematise the programme)
5	**Implement and document activity**	Who will document the lesson, the teacher or the students? Emphasise what the student does, documenting also students' outputs, either verbal, written or performed
6	**Reflect on the activity**	Consider programme, goal and motive achievement reflecting on practice supported by evidence from documented activity

4.7 Coda

In this chapter, besides presenting a tool and process to document activities in the SLS, the Pedagogical Graphic Novel, I departed from a reinterpretation on some of the concepts of Activity Theory to develop the Science Learning Studio Activity Analysis Methodology and a tentative model for curriculum development in the SLS. A practical application of this Analysis Methodology will be made in case study 2 in section 6, on a practical Science lesson in year 10 Science.

5. Developing a methodology and a meta-tool for the entire research project

To answer the research questions of this study, I designed a 3-stage methodology considering a progressive focusing, from a more qualitative to a more quantitative stance. The first stage was a case study with an ethnographic approach, followed by a set of 5 case studies, finally ending with a survey. The first case study of open inquiry Science took place in Externato Cooperativo da Benedita, near Alcobaça (ECB). The next case study (2) was of a practical Science lesson in a school in the Lisbon region, resorting to classroom observation. Three more case studies were made, the first (3) in a school in the Oporto district, concerning the elements of the Science Learning Studio in use, using a walkthrough interview to an head of facilities to understand in detail how the elements of the Science Learning Studio were viewed by a teacher, and finally two case studies, one (4) in a school in the Algarve region, analysing the work of an operational assistant responsible for the organisation and management of one SLS using contextual task analysis, and the last (5) in a school in the Setubal region, concerned with analysing the organisation and management activity in the Science Learning Studio from the point of view of teachers and head of facilities, also using contextual task analysis.

Finally, a survey was designed with some of the inputs from these case studies to answer most of the research questions.

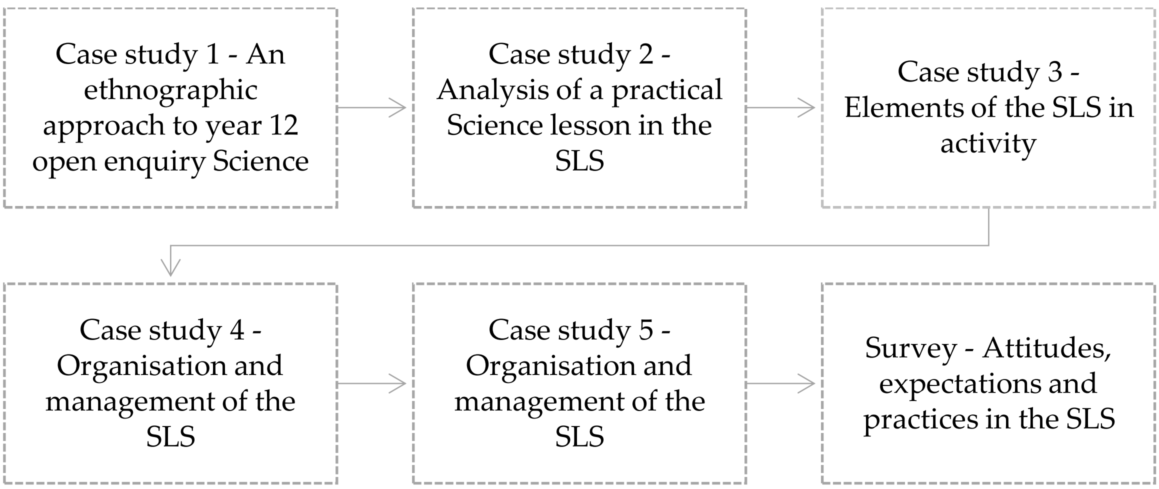


Figure 5.1 – Schema of the methodology

The several methods used will be substantiated in the remaining chapters, when introducing each of the case studies and the survey[3].

During the research project funded by FCT, to which this thesis relates to, the mixed methods approach to the research questions began with case studies involving classroom observation, interviews and later a survey to teachers using the SLS. It became evident early on in the research process that trying to connect such diverse capture methods and data analysis would be a complex task. Besides this methodological issue, I felt that efforts to coordinate the project as a whole could be improved if we used adequate project management and collaboration tools.

A look into the literature could help map all the activities of the research process and start to address these challenges in a more structured and consistent way. From Miles & Huberman (1994) I understood that a qualitative research process may involve:

1. Collaborating;
2. Reviewing the literature;
3. Generating data;
4. Storing, protecting and managing data;
5. Searching;
6. Transcribing;
7. Memoing;
8. Editing;
9. Coding;
10. Data linking;
11. Analysing content;
12. Data displaying;
13. Graphic mapping;
14. Writing;
15. Research project managing.

One possible way forward would be to use a QDAS (Qualitative Data Analysis Software) package. Despite the focus on data analysis, this highly advanced software is evolving to provide support to many of the above activities. After exploring some of these tools with collaboration and project management in mind, I considered the learning curve high for some team members, its analytical

[3] Part of this introduction and sections 5.1 through 5.6 are based on an unedited draft of the case study accepted for publication in SAGE Research Methods Cases in Education: Fernandes, J., & Barbeiro, L. (2017). *Coordinating diverse research practices using digital research notebooks: a case study in Science Education*. Thousand Oaks, USA: SAGE. http://dx.doi.org/10.4135/9781473993983

features were too high-end, the costs were significant and there was a need for easier integration of the software in the diversity of individual working processes and tools. If QDAS excelled in the central analytical phase of a research project, it still did not provide the best support for all the stages and activities of the research project.

Table 5.1 - Research activities and digital tools used before developing the concept of Digital Research Notebook

Research activity	**Tools**
Collaborating	Google Drive, Office Online and Skype
Reviewing the literature, generating data and memoing	Adobe Acrobat Professional, Evernote, Microsoft OneNote and Mekentosj Papers
Storing, protecting and managing data	Dropbox, Bittorrent Sync, Beyond Compare and Synctoy
Transcribing, analysing, coding and data linking	NVivo, MAXQDA, Atlas.ti
Data linking and graphic mapping	VUE, Mural, NVivo
Writing	Adobe InDesign, Google Drive, Microsoft Word, Word online
Project managing	Folders, Google Tasks, Trello, Google Calendar

With this in mind, together with Luis Barbeiro, a MPhil/PhD programme colleague at King's College London and a consultant to the research project, we began developing the concept of Digital Research Notebook (DRN), not as a way of eliminating this diversity of tools and processes or replacing QDAS for deep analytical purposes but to provide a common ground that supported research activities as a whole.

We engaged in a search for platforms that could provide the coordination we were lacking. We tried several project management and collaborative platforms, collaborative design and innovation platforms, mostly business-oriented, but remained unsatisfied. We ended up resorting to a tool that we had already been using for several research projects in a simpler way – Microsoft OneNote.

OneNote is usually portrayed as a digital notebook for general audiences. It has meanwhile encountered several applications in education, but not in qualitative or mixed methods research, as far as we know. We had used OneNote for research notetaking, memoing and literature reviewing for more than 8 years. Facing difficulties in coordinating our research practices and supported by the research literature on software for qualitative research (e.g., the work of Paulus et al., 2014; Silver & Lewins, 2014), we developed procedures and templates which made OneNote a useful digital tool for our entire research process. We named these notebooks tailored to our research DRN.

In the following sections I will describe several practical issues that arose in this research project focused on my own work and on how DRN helped me deal with the myriad of activities involved in the entire research process:

1. Collaboration (e.g., writing a paper collaboratively);
2. Project and data management (e.g., task management);
3. Literature review (e.g., annotating publications collaboratively);
4. Field work and data analysis:
    a. Interviews (e.g., collecting audio and handwritten notes in an integrated way);
    b. Classroom observation (e.g., a workflow to produce pedagogical graphic novels);
    c. Survey (e.g., making the dataset and design process open).

Some of the figures used are intended to represent the general concept and are not intended for detailed reading.

5.1 Collaboration

I will now describe and analyse an example of collaboration in the research project, writing a paper collaboratively, by focusing on its practical features. I will try to illustrate a scenario of how we did some of the collaborative writing in previous projects, the challenges that arose and how we developed the DRN to find better ways of working in the project.

5.1.1 Exploring creativity – Connecting different sources

In the process of writing a paper, we would begin by discussing ideas, mentioning some articles, etc. and jotting down some notes about it. We would then write a provisional index of topics and sort which parts each person would write. This was usually done in a meeting and the draft index would be emailed to the group.

Using the DRN allowed us to better explore these first stages of writing. For a creative brainstorming, we developed a Canvas template with the possibility of writing anywhere, very like what can be done with post-its on a wall.

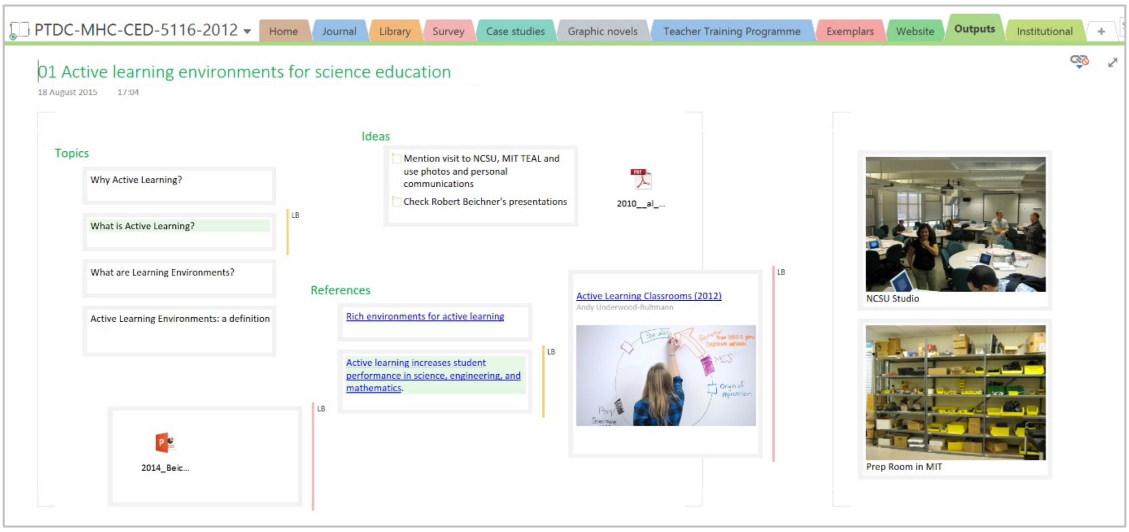


Figure 5.2 - A collaborative open canvas for writing a paper, from the initial brainstorming to the definition of a provisional index

This made a considerable difference in sparking creativity. It was more versatile than just playing with post-its, because it allowed us to place text, photos, screen clips, videos, drawings and files all in the same place, zooming into certain areas of the canvas to focus on a theme or zooming out to get a bird's eye view of the entire canvas. We could also move these elements in the canvas, connect them, sort them, etc. and thus explore our ideas more grounded in data. From an initial chaotic display of things, we ended up with an organised collage of data. This made easier to create a provisional index for writing and have available information we could readily use to develop the paper. And there was no need to email the provisional index as it was done in a notebook page shared between the authors.

5.1.2 Grounded writing - Keeping your sources close

Before using a DRN, on receiving the draft index by email, we would then work individually in a word processor of choice and use our own personal way of writing. We would add pieces of previous texts, write and rewrite new text, add citations, notes on sources, comments, etc. We tried to keep a close connection between what we were writing and the sources of information that inspired that piece of text or worked as evidence. We would usually make a note to direct us to it, in the form of a link to a file or source but this was very cumbersome to make and follow.

Writing in the DRN solved the problem of relating the writing with the actual sources, making it more grounded. Besides writing, in the DRN pages, we could insert any type of file (PDF, Word, Excel, PowerPoint, photos, audio, video, etc.). This meant that at the end of any paragraph we could have the actual source, or a link to it in another notebook page.

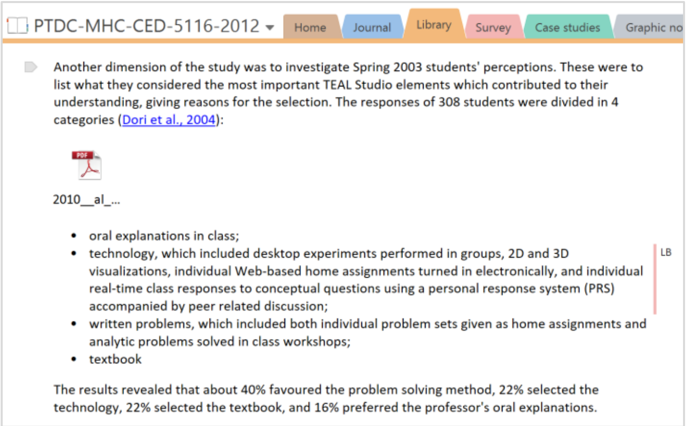


Figure 5.3 - An example of writing in a grounded way, keeping sources (in the case a PDF) accessible across the text

This linking ability between text and files extended also to text paragraphs. With a few clicks we could make a link from one paragraph to another.

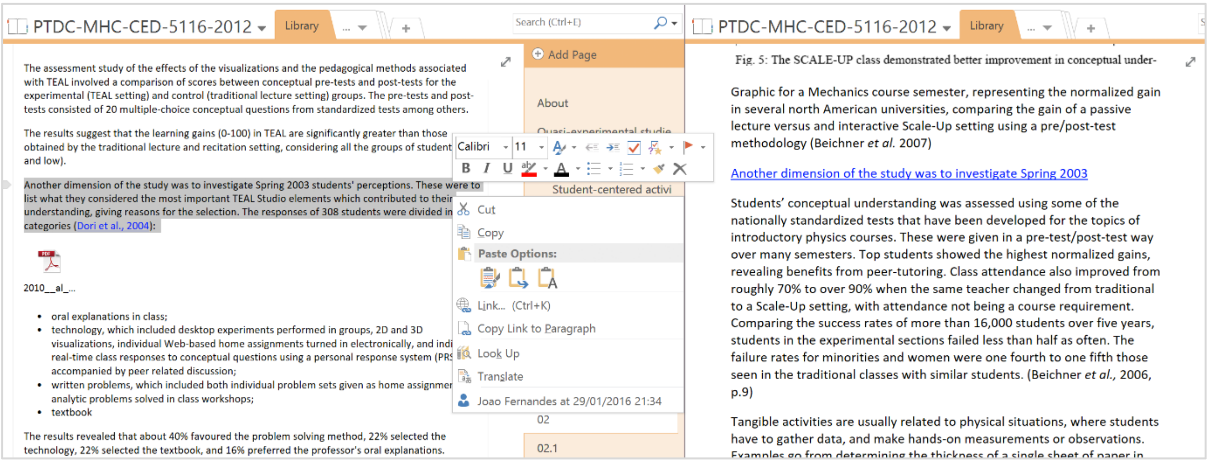


Figure 5.4 - Linking paragraphs of text can improve depth of analysis, by selecting "Copy link to paragraph" in the destination text and pasting it into another text

We now had the ability to better grasp, compare and analyse different pieces of texts and make our writing more creative and grounded.

5.1.3 Bridging the gap between individual and collective writing

Before using DRN, when the individual writing of each topic had evolved and was clear enough, we would put our writings together in a single common file (usually in Word) and share it between authors.

We would then read each other's work and use the review features (comments, track changes and versions) to make suggestions, corrections, etc. The file would be sent back and forth by email and if this became too frequent, we would place the file in a shared cloud drive (Dropbox, Office Online). We would then email each other or use a VoIP application (Skype) to report the status of the document, or to request comments or follow-up.

When we were together we could write on the same piece of text while discussing it. In an online meeting this would be done using the sharing screen feature. Sometimes, when we really needed to advance the text faster, we would use Word Online to edit the text at the same time.

With the DRN our work became collaborative from the start. Instead of working individually in separate Word files, each of us worked on different pages in the same notebook section. The pages in the DRN are organised similarly to a pen and paper notebook. In the Output section created in the DRN, in the page group dedicated to the paper, we would have a page for each topic (and sub-pages, if needed). Each page would initially be attributed to an author and later reviewed by everyone.

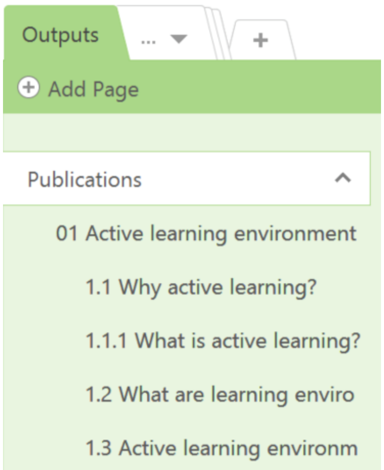


Figure 5.5 - In a way similar to a paper notebook, the DRN is organised into sections, with pages and subpages

Having all the writing in the same place and everyone with easy access to it made a difference in the way we communicated and wrote. The ability to quickly skim through each other's texts also let us have a bird's eye view of its progress.

When we needed to write collectively in a single page, OneNote had a set of unique features that supported our collaborative writing:

1. Turning to bold the title of every page recently edited by other authors;
2. Highlighting all the new edits in a page with a green background;

3. Identifying the last author of each paragraph of text, through a coloured ribbon with the author's initials on its right side;
4. Searching for recent edits, by author, on a certain page or section;
5. Using visual tags (like To Do) in paragraphs to comment, ask questions, etc.

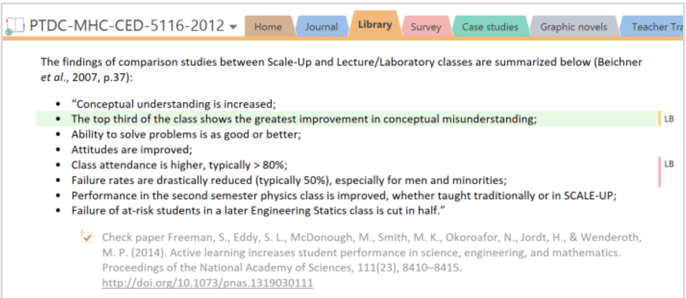


Figure 5.6 - OneNote has multiple collaborative features, such as showing the initials of the last author of each paragraph on its right side, highlighting the background in green for unread edits, etc.

All this would let us know about recent edits, which part of the text was written by whom, easily follow-up changes or comment directly with the author.

We would work on the text in the DRN until it was ready for final editing. For this final stage, we would export the notebook pages to Word to apply formatting, count words, number pages, insert references, etc. When working on the final version of the Word file, we would place it in OneDrive to work synchronously and online on it. We would also insert the file in a notebook page, to have easy access and to archive the final version.

5.2 Project and data management

In previous research activities, project management was usually done informally, without much effort put into it. We were confronted with a series of difficulties while trying to manage the project collectively and as a whole. Through the DRN we tried to find solutions to task and time management, logging, auditing, analytical and institutional data management.

5.2.1 Task management

In project meetings, we would decide on the next steps and attribute tasks to each colleague. We would then jot down a few points or make a meeting minute. The minute would later be shared by email with everyone. Sometimes more detailed lists would be done individually by the person in charge of the task to better organise it and control its development.

If the tasks demanded deeper collaboration, we would write To Do lists in a shared Evernote notebook. Though useful, this would usually become an *infinite* list full of left over To Do tasks.

The DRN opened the possibility for a finer grain management of the project.

The way we defined tasks became clearer and better grounded on the actual work we were doing. In the DRN tasks could be written as checkboxes in the actual page or piece of text where they originated. We did not have to move to a Tasks' page to write them down, losing focus or separating the context from the task.

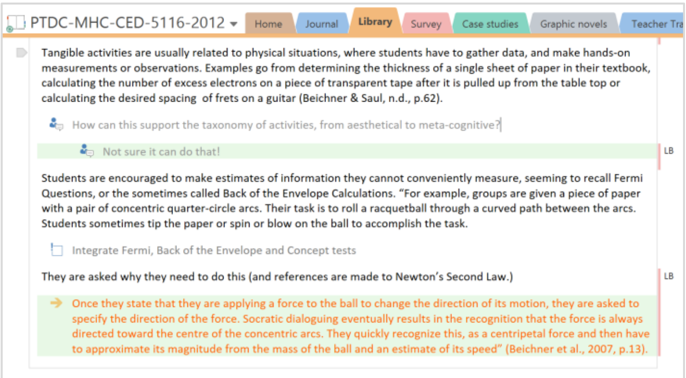


Figure 5.7 - Tasks can be identified with checkbox tags and applied in context. Tags can be customised with icons for different types of tasks (To Do, To Think, Comment, Important…)

Besides the To Do checkbox tag, we developed a simple collection of visual tags that let us leave notes to oneself and others to manage our activities. We called them processual tags, as they facilitated the moving forward of the research processes: to-do, to-think, important, comment, common, etc. This tagging was also made in context. Following up tasks became simple as the DRN was able to harvest all the tags from a page, section or notebook, through a "Find tags" feature. This gave us a bird's eye view of what was significant and had to be acted upon. We could even generate summary reports of the tags, by author, type or date, facilitating the way we managed our tasks.

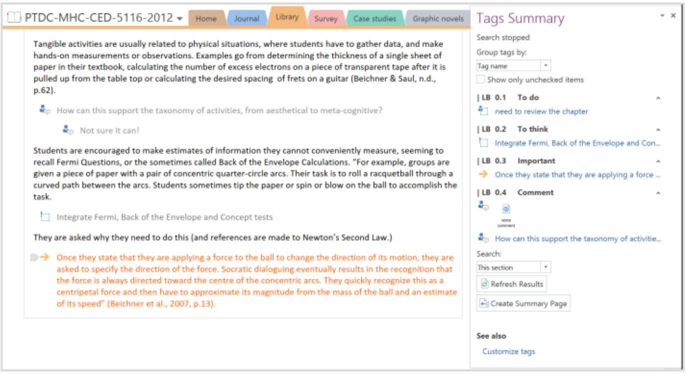


Figure 5.8 - Tasks can be searchable by page, section or notebook, by author or time. Tag summaries provide a quick report of tasks (all or just unchecked items)

5.2.2 Time management

For time management purposes, such as organising meetings, defining deadlines or scheduling field work, we started using a shared Google Calendar or Doodle.

With the DRN we could add a time tag to any task, like today, tomorrow or specific to a date and time. Timed tasks were automatically integrated with Outlook tasks and could be viewed in the application. We could then add reminders to these tasks to get for example alerts on our mobile phones.

5.2.3 Logging and auditing

For the team to follow what was happening in the project, we tried to integrate the tasks with a calendar (Outlook or Gmail) to generate a kind of log of all activities. This was something that was never easy to achieve and the detailing of so many small tasks was not helpful.

To solve this, in the DRN we decided to develop a Logger, a calendar-like section, where we collectively added the main themes being worked on that week, with direct links to the section or pages in progress.

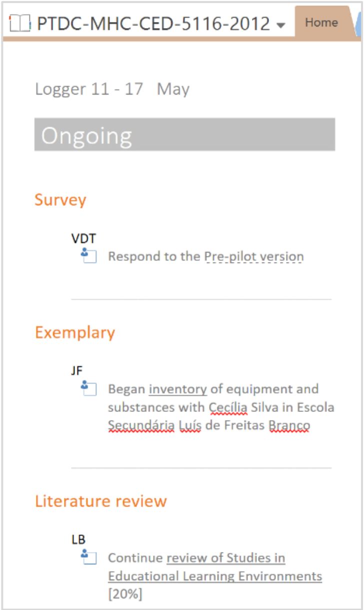


Figure 5.9 - The Logger provides a bird's eye view of the ongoing project. It can help every member of the team to follow the main topics being worked upon

We also thought of maintaining a collective Research journal where we would periodically collect the significant moments of the research: significant readings, data, insights, reflections, events etc. To have reflective purposes, the journal was multimedia and had links to the information sources elsewhere in the notebook. Any participant could edit or comment it. We developed a Graphic Novel template to collect information from other parts of the notebook to make this journal easy to follow. This format could also be useful in showing other stakeholders how the research process was going.

These two features, the Logger and the Research journal, linked to the content of research, could, we believed, make our research process more open and our work more auditable and ethical.

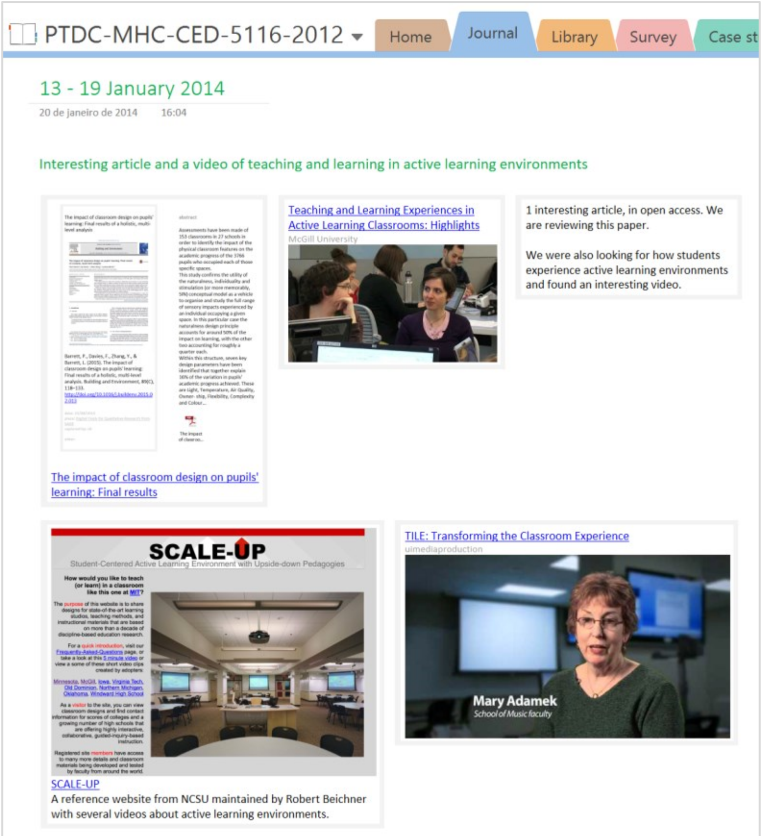


Figure 5.10 - The Collective Research Journal shows the relevant moments of research in a multimedia graphic novel style, for reflective purposes and for keeping stakeholders informed

5.2.4 Data management

Before developing the DRN, we captured the many data files (interviews, classroom observations, etc.) with cameras, audio recorders and handwritten field notes on paper. Photos, audio and video files were then stored locally and organised into folders. To share these local files we used cloud services (Dropbox for non-sensitive documents and Bittorrent Sync for sensitive data that required encryption). Such dispersion in the data hindered our capacity for analysis, mostly when we wanted to work together on it.

Resorting to the DRN changed the way we captured data. OneNote allowed us to capture directly into a page: photos, audio, video or external files. We were able to organise them in custom pages, which we called Collectors, adding information on capture contexts, metadata, summaries, etc.

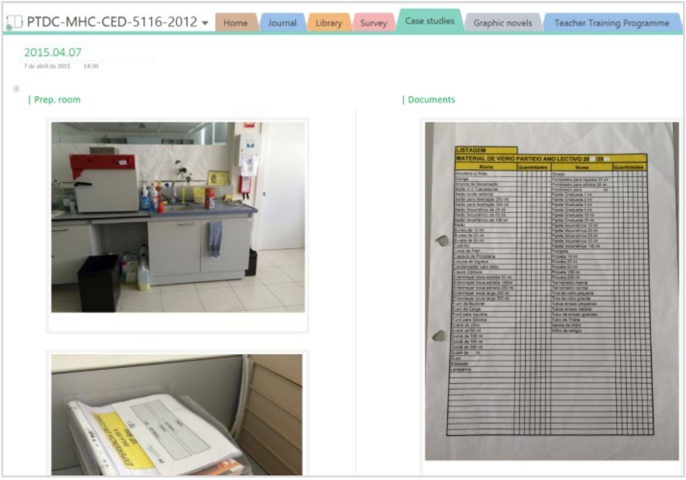


Figure 5.11 - A Collector facilitates the organisation of data capture in any format

We also had to manage general information related to the research project, such as emails, grant application documents, acceptance terms, regulations, accounting, etc. These files would be previously organised in folders or email applications and disconnected from the research data.

With the DRN we put disparate information together and easily accessible. The previous problem of managing email information of common interest to the project was easily solved through the ability of Outlook to send emails directly to OneNote. This made possible the creation of a repository of relevant emails.

All the information, now in one place, could be easily shared and collectively organised, facilitating search and linking, fostering analysis at a deeper level. General information was closer to the data and analysis, making the management of the project as a whole easier when we needed to write reports, ethical approvals, etc.

For backups of the DRN, we had several versions automatically set by OneNote, in the computers of every member of the team, and the version history of each page accessible in the DRN.

Figure 5.12 - The Institutional section integrates general information related to the research project, such as emails, grant application documents, acceptance terms, regulations, accounting, etc.

5.3 Literature review

The literature we were interested in for this project was quite diverse. Some was acquired in paper or digital, other was available in online repositories or came from personal collections. We made the effort of scanning some of the publications with OCR (Acrobat Professional XI) and defining a common format for our digital library (PDF), later organised in a reference management software (Mekentosj Papers). We could make full content searches of all the publications and comment and annotate them.

5.3.1 Creating a Library section in a Digital Research Notebook

We started developing Library sections in our DRN for specific themes. The sections were organised by themes and in Publication Collector' pages. We added the PDF file of the publication to each page, along with some metadata and a summary review. The files in the notebook could still be shared with the reference management software if they were imported from a common cloud drive (like OneDrive or Dropbox), keeping the access to the latest version of the file.

Figure 5.13 - In the Library section of a DRN we placed several Publication Collectors. In this template, we could add a cover, the PDF, some metadata, a summary of the publication and a reading memo

5.3.2 Annotating publications collaboratively in one place

Most reference managers allow annotations in PDF but relating texts excerpts within and between papers or moving your annotations for further editing is more demanding. This turns analysis into a cumbersome process. If you add collaboration to this, the problem grows exponentially.

This led us to develop a workflow to make collaborative annotations, linking and tagging/coding that made possible a more in-depth analysis of the literature.

With the PDF opened from its Publication Collector, we would place it side by side with a Literature Review Matrix template – a series of columns with card like cells - and then copy excerpts from the PDF and paste them in the cards. In PDFs protected from copy/paste we would use the OneNote screen clipping tool and cut and paste the screen region of the paragraph we were interested in collecting, and then apply the feature of text recognition in images, pasting it in the cards.

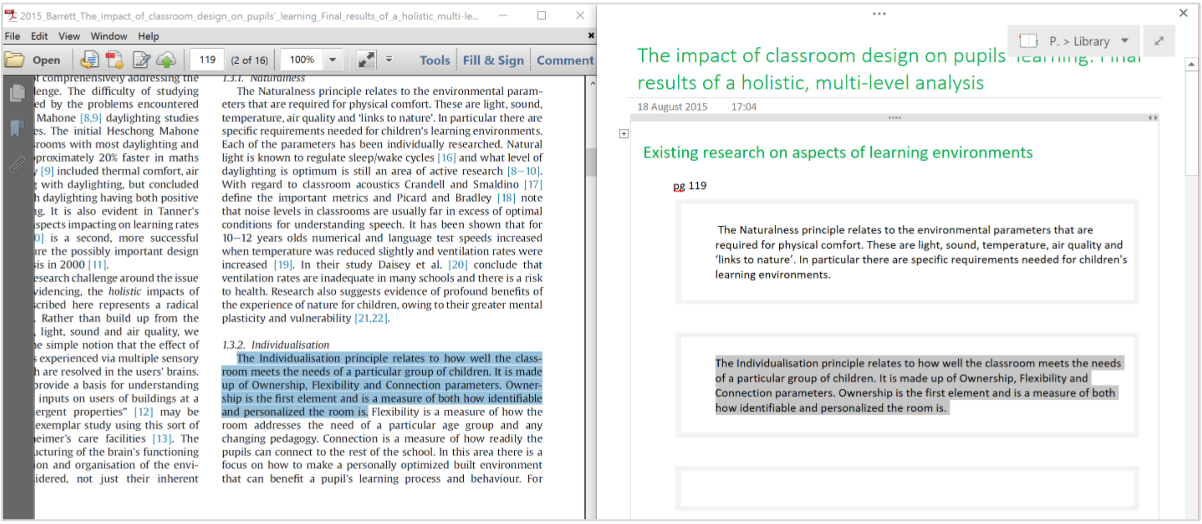


Figure 5.14 - To analyse a text, excerpts from PDF can be copied and pasted in a Literature Review Matrix template – a series of columns with card like cells.

What OneNote offered, more than extracting and compiling texts from publications in an organised way, was the possibility of using on the selected texts a set of manipulation tools (highlighting, outlining, drawing upon) and most of all, the ability to link and tag paragraphs.

5.3.3 Linking and tagging paragraphs

Linking paragraphs of text within the same page or between any paragraph in any other section in the notebook proved to be a very grounded and in-depth analytical procedure, facilitating comparison of sources, prioritising, theming, etc.

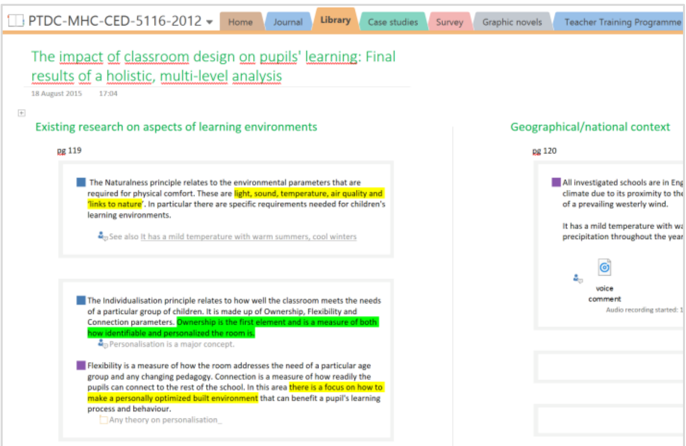


Figure 5.15 - In the Literature review matrix, paragraphs of text can be linked between each other, tagged for task management or coded as in a QDAS

In the DRN we also created custom tags, like codes, that would be applied at a paragraph level, similar, though simpler, to coding in QDAS. This allowed us to make a tag search and extract the relevant texts across our entire library, along with the comments made on them. We could also generate summary pages of that search. Manipulating text in this way offered deeper and better-grounded insights. When we needed further detailed analysis we could resort to QDAS, but the balance between effort and depth in the DRN was adequate for many of our analytical questions.

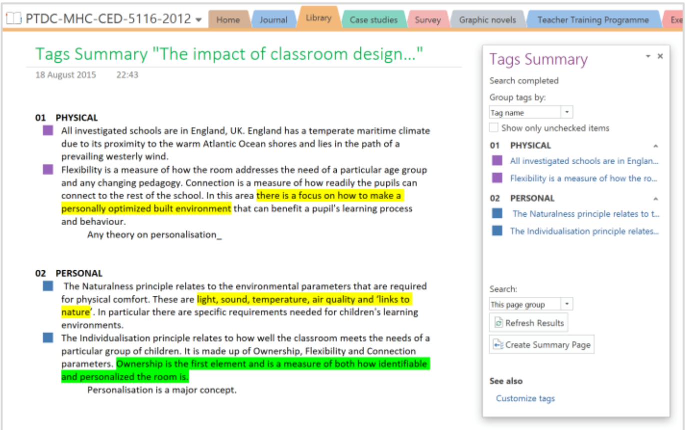


Figure 5.16 - Codes can be searched and coded segments can be collected in a Tags Summary page

5.4 Interviews

Another method used in this research project was a walkthrough interview schedule that provided a spatial agenda for participants to respond to. I wanted to elicit the practices associated with the key design elements of the Science Learning Studio and contrast them with the idealised model. This meant that the interviews took place in the actual Studios, where the interviewer and interviewee could directly interact with the space and objects. I used a visual checklist that defined a route through the Studios, with some key stops where questions would be made.

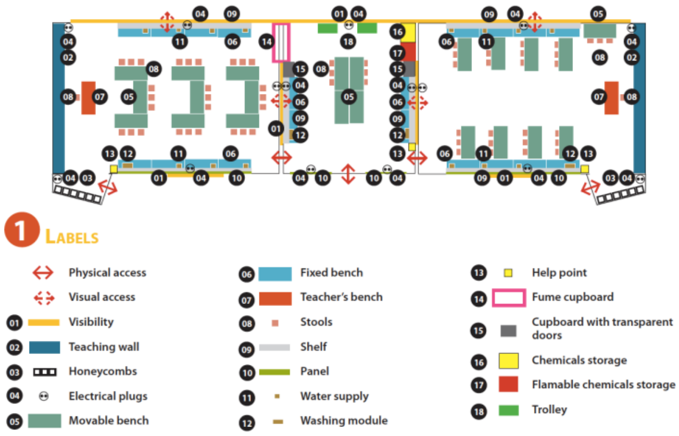


Figure 5.17 - Key elements of the SLS drove the interview route

5.4.1 Collecting audio and handwritten notes in an integrated way

This kind of interview meant that the interviewer and the interviewee were constantly moving in both the Studio and prep room, exploring, changing the space or demoing some applications, while:

1. Recording the interview (audio);
2. Taking photos;
3. Taking handwritten notes.

The pilot interviews and photos were recorded with a mobile device and handwritten notes were taken in a paper notebook.

The immediate problem arising from this was the difficulty in linking all these data. The digital files were usually stored in a folder by file type and interview date, if in a digital format, or linearly in the field notebook on paper, with post-its acting as separators. So, how to make them manipulable in a common working space for research purposes?

We developed a Handwriting template in the DRN that could be used with a tablet and pen by the interviewer during the interview process. The interview schedule was at hand in the same section to help the process. In this template we would directly record the audio of the interview, include the photos taken and handwrite our notes. The information was in this way kept all in one place and usefully synced. This meant that when we played the audio recording, the handwritten note taken at the time of the capture would become highlighted (and vice versa).

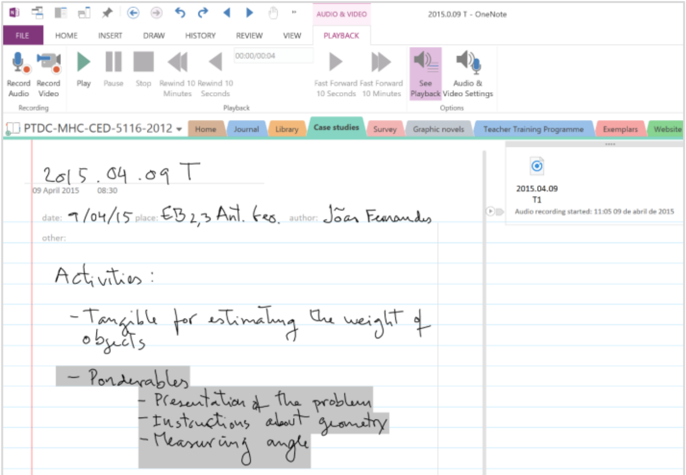


Figure 5.18 - In an Interview, handwritten notes were captured and synced with the audio

To recover some old interview data, we devised a workflow to easily scan notebooks with a mobile device, using Office Lens, and then add the scans to the DRN. We also tested a smart pen that writes in plain paper but can send all the text and drawing to OneNote. All the digital handwriting could be accurately converted to text in the application.

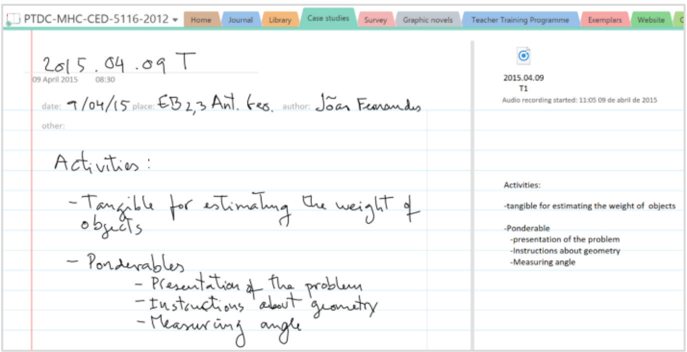


Figure 5.19 - Handwritten notes can be accurately converted to text with the "Ink to text" function in OneNote (notice the captured text on the right)

Though working with paper and digital was quite difficult at the start of the process, mixing paper and digital workflows through the DRN became quite manageable.

5.4.2 Transcribing the interview

OneNote provides a basic interface to support transcribing of audio or video interviews. We can play the recording forward and backwards, jump to a specific time tag, and in this way, transcribe the entire interview. We can later sync the transcription with the audio by simply adding paragraphs to the text in the moment we were listening to it. With this syncing in place, when we played the audio again, the corresponding text would be highlighted and if we played the text (a small play button is added to each paragraph), we could listen to the matching audio. This made it much easier to quickly access the context of the talk while doing analytical work.

Figure 5.20 - Audio can be synced with the transcription. When the audio is played, the corresponding transcription is highlighted and vice-versa

From this transcription, we could apply all the features of OneNote such as tagging, searching and linking, providing more opportunities to ground our overall research work.

5.5 Classroom observation

The goal of classroom observations in the project was to analyse activities using the Science Learning Studio Activity Analysis Methodology. In this section I will show you how I collected multimedia data in a Digital Research Notebook in an integrated way, processing it and finally generating a Pedagogical Graphic Novel, a kind of storyboard of classroom activities.

5.5.1 Collecting data in a coordinated way

In the pilot phase of the project, we began generating data from classrooms using a camera to record video, take some photos and registering observation notes using Evernote.

A significant problem with this data collection process was the difficulty in syncing the available data in a common timeline without some considerable effort. We had photos in one folder, video in another and notes yet in another place. Handling large video files and doing collaborative analysis was also very demanding.

Our vision for classroom observation methods was that they could be a meaningful process not only to researchers, but also to students and teachers. For pedagogical and professional development purposes, we also thought of classroom observation as an opportunity to produce shareable outputs of real classroom practice. To address all these challenges, we designed a participatory workflow for producing Pedagogical Graphic Novels.

5.5.2 A workflow for producing Pedagogical Graphic Novels with DRNs

From previous experiences using storyboards to capture classroom activity, already mentioned in chapter 4.1, I decided to produce a graphical output of the classroom observation, to easily communicate classroom activity, in both paper and digital formats. I revised the storyboard concept and reframed it as Pedagogical Graphic Novel.

I still needed to design a workflow easy enough to sync the several data types (notes, photos, audio/video and files), allow analysis and generate a flexible output, keeping its participatory and collaborative nature.

The first step was to provide one student with a tablet with internet access and instruct him/her to capture classroom activity, by taking photos and writing captions on a DRN page. I was connected to this same page in another device, recording classroom audio.

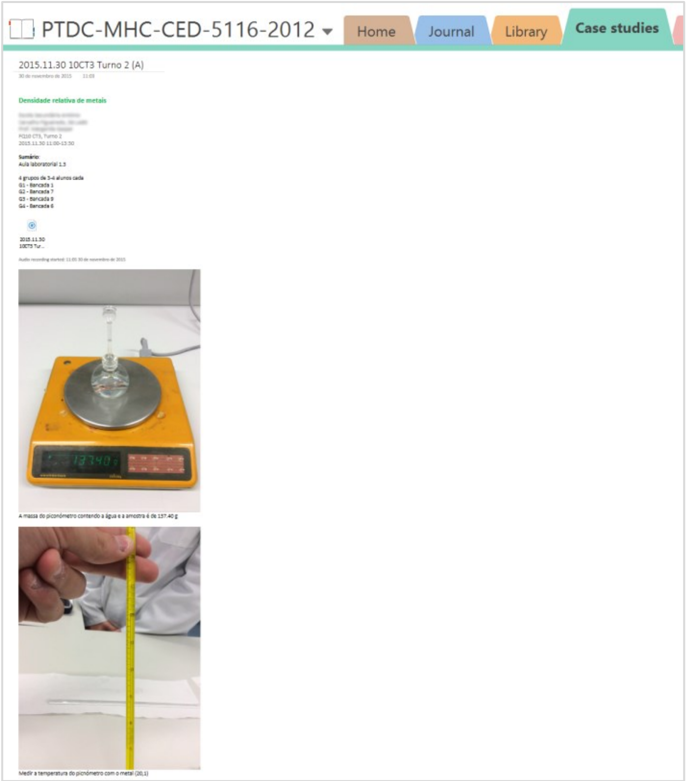


Figure 5.21 - Students capture vignettes of activity during class, adding photos and captions

In this way, I could follow the student's capture in real-time, and give him/her just-in-time feedback on the relevance and quality of the capture.

By the end of the class, I would review the photo capture and captions made by the student, cropping images in the DRN to focus its key aspects and composing them into a Graphic Novel template.

Finally, I would sync the audio with the captions so that when I played the audio, the text would be highlighted and vice-versa.

I also created links from parts of the text to data collected in other formats (for example, PDF files or PowerPoints used in class), or transcribed certain interactions, providing more detail to the graphic novel.

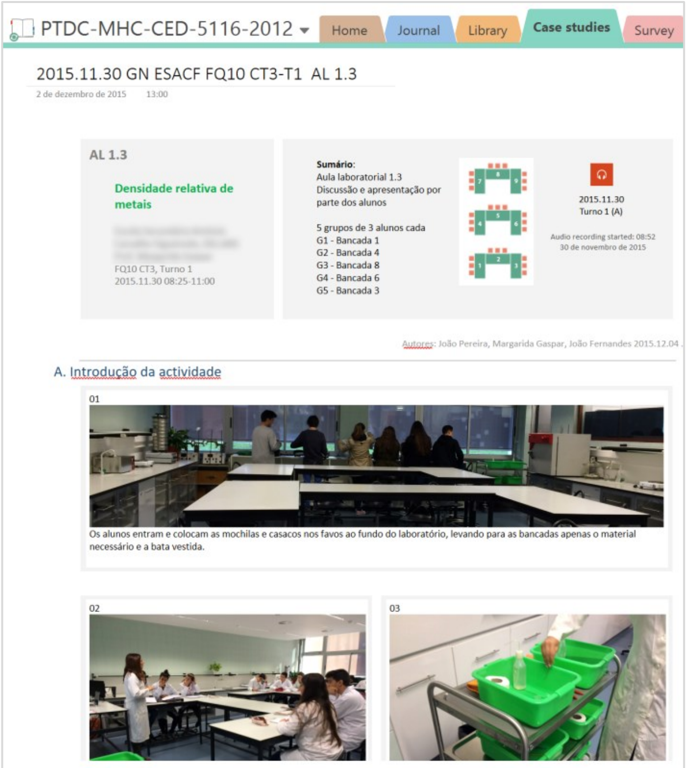


Figure 5.22 - The Pedagogical Graphic Novel integrates several modalities in a flexible format

This first draft of the Pedagogical Graphic Novel was then edited with the teacher. Besides correcting it, we discussed aspects of the activity relevant to the research project and identified the issues that could be raised when discussing the novel with the class.

In the class following the recorded one, I would project the graphic novel in class and analyse and review the activity collectively, with the vignettes framing the discussion. During the discussion, more changes were done to the novel.

This workflow finished with publishing the graphic novel in PDF and paper formats. For that, we developed a template in OneNote formatted to print in an A3 paper size in landscape mode. With one click we exported it to Word, where we added page breaks, page numbers or headers, and then exported the result to PDF or print. The novel had as authors the student, the teacher and the researcher.

5.6 Survey

In this section I will describe how the survey was developed, illustrated and shared in a DRN.

5.6.1 Defining the survey questions

I wanted to integrate themes from several other surveys to have a reference to which to compare some of our results.

I began by using Word to prepare an early draft and to start iterating versions. Then, I pasted several questions from different sources, my own ideas from the research questions, and tried several structures with heading styles. This file would then be shared among the team, usually in a cloud service, and commented and worked upon.

We felt some difficulties in dealing with the linear flow of text of a word processor in this conceptual stage so we started using the DRN to compare and sort interesting questions from previous surveys. We copy/pasted them from PDF into a Matrix template designed for this end, in which they could be easily put side by side, zoomed in and out and combined with other modalities other than text. We could also have different OneNote pages opened side by side which allowed a much easier comparison between questions and the Matrix with the overall design ideas.

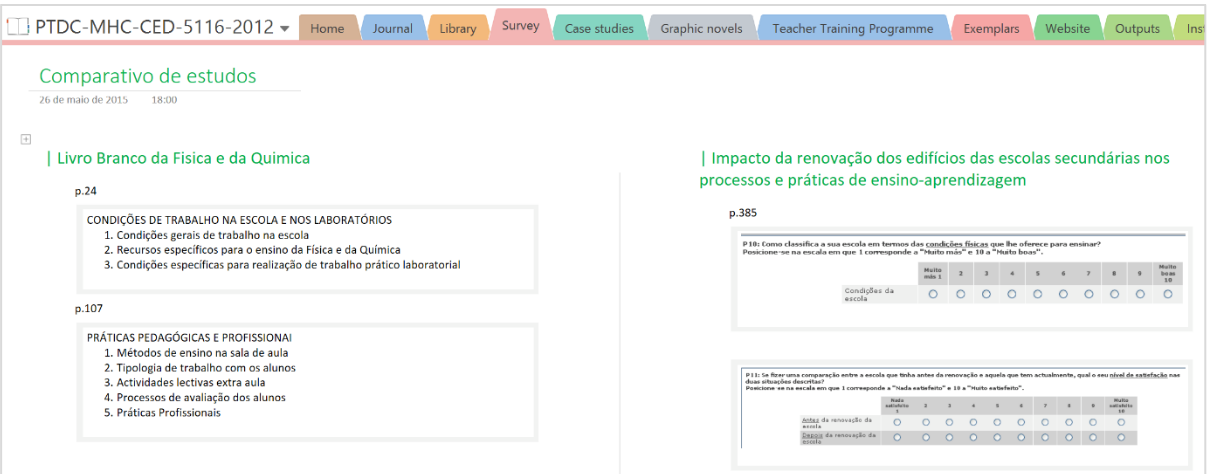


Figure 5.23 - We used the Matrix template to compare different studies that informed the survey questions' design

We began iterating drafts in OneNote using the outline feature to comment on each question. This made collaboration easy between the team to get to the final version before validation.

5.6.2 Illustrating elements of the survey

I planned a visual approach to the survey, with illustrations and photos of classroom activity that could help respondents to reflect on their own practices.

The survey was sent to teachers from 106 schools intervened by Parque Escolar. The questions were organised into 5 categories: 1) Basic data on the respondents; 2) Use of the new SLS; 3) Teaching and learning activities in the new SLS; 4) Experience during the intervention by Parque Escolar; 5) Detailed data on the respondents.

Photos from graphic novels were the obvious content for section 3 of the survey. But in section 2, we wanted to show diverse situations of the SLS in use, so that respondents could have a concrete situation to respond to.

Initially, I made several experiments with a 3D model of the new SLS in Google Sketchup. The goal was to assess the practicality of a workflow to create short illustrated activities in the SLS. The initial process was somewhat complex - define the framing in Sketchup and export pictures, print them in paper, draw upon characters and objects and scan the result. This workflow was tested with a friend, Susana Vicente, and was not practical.

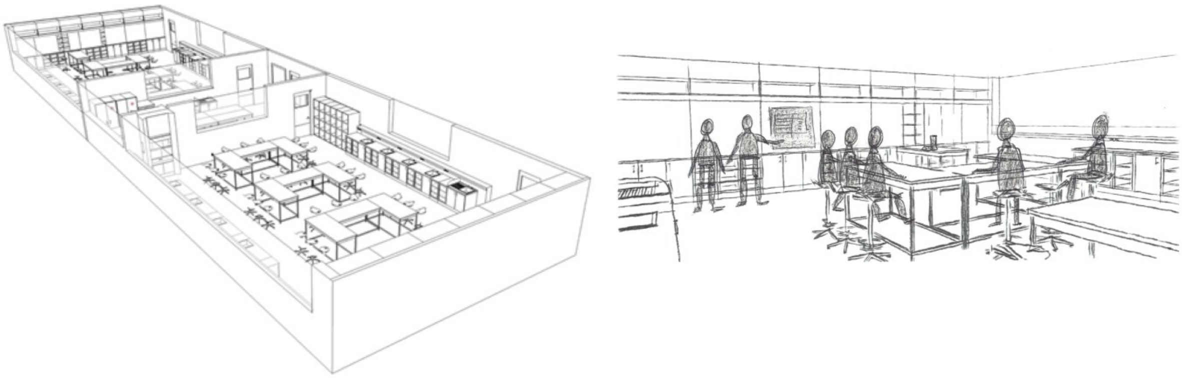


Figure 5.24 - After exporting a framing in Google Sketchup as a picture, we would print it, illustrate it and finally scan it.

So Luis began some experiments using digital ink in OneNote to create simple characters and objects, which would then be overlaid on the Sketchup frames. This proved to be a simple workflow. This also allowed reuse of characters in other illustrations.

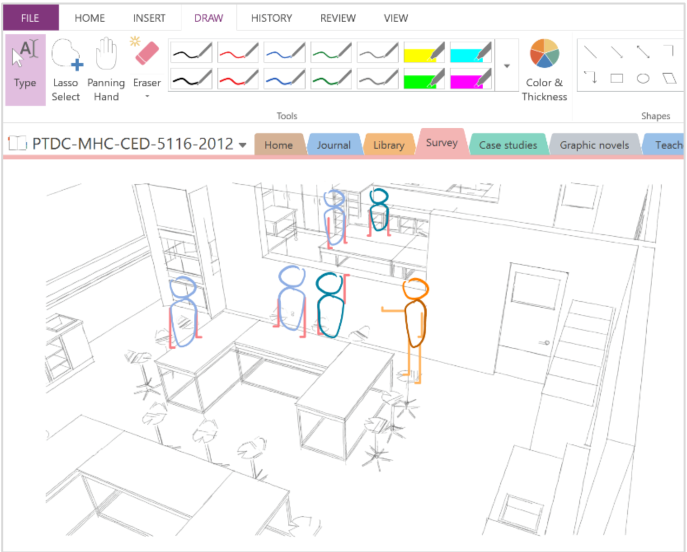


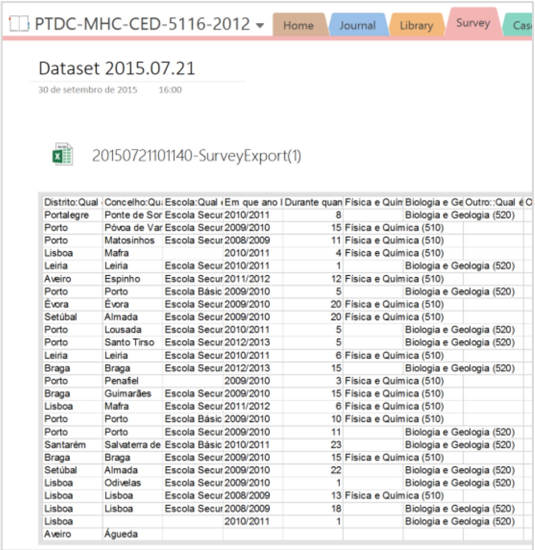
Figure 5.25 - Drawings, free-form or geometric, can be made in OneNote with great accuracy using a stylus

5.6.3 Making the dataset and design process open

From the start, I wanted to make the raw data and the results of this survey available to both respondents and the wider research community. The initial strategy was to use the survey software features to share the results automatically with the respondents and later, to make the data and results available online.

I used SurveyGizmo to manage the email campaign, deliver the online survey and report on the results. This tool had the possibility to share with respondents both their individual responses and the results' report.

For the remaining stakeholders, I used the DRN to share the dataset (embedded as an Excel file), the data analysis reports (PDF), the outputs (as papers) and the development process, from survey design to validation and implementation (a set of OneNote pages).



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Porto	Póvoa de Var	Escola Secur	2009/2010	15	Física e Química (510)			
Porto	Matosinhos	Escola Secur	2008/2009	11	Física e Química (510)			
Lisboa	Mafra		2010/2011	4	Física e Química (510)			
Leiria	Leiria	Escola Secur	2010/2011	1		Biologia e Geologia (520)		
Aveiro	Espinho	Escola Secur	2011/2012	12	Física e Química (510)			
Porto	Porto	Escola Básic	2009/2010	5		Biologia e Geologia (520)		
Évora	Évora	Escola Secur	2009/2010	20	Física e Química (510)			
Setúbal	Almada	Escola Secur	2009/2010	20	Física e Química (510)			
Porto	Lousada	Escola Secur	2010/2011	5		Biologia e Geologia (520)		
Porto	Santo Tirso	Escola Secur	2012/2013	5		Biologia e Geologia (520)		
Leiria	Leiria	Escola Secur	2010/2011	6	Física e Química (510)			
Braga	Braga	Escola Secur	2012/2013	15		Biologia e Geologia (520)		
Porto	Penafiel		2009/2010	3	Física e Química (510)			
Braga	Guimarães	Escola Secur	2009/2010	15	Física e Química (510)			
Lisboa	Mafra	Escola Secur	2011/2012	6	Física e Química (510)			
Porto	Porto	Escola Básic	2009/2010	10	Física e Química (510)			
Porto	Porto	Escola Secur	2009/2010	11		Biologia e Geologia (520)		
Santarém	Salvaterra de	Escola Básic	2010/2011	23		Biologia e Geologia (520)		
Braga	Braga	Escola Secur	2009/2010	15	Física e Química (510)			
Setúbal	Almada	Escola Secur	2009/2010	22		Biologia e Geologia (520)		
Lisboa	Odivelas	Escola Secur	2009/2010	1		Biologia e Geologia (520)		
Lisboa	Lisboa	Escola Secur	2008/2009	13	Física e Química (510)			
Lisboa	Lisboa	Escola Secur	2008/2009	18		Biologia e Geologia (520)		
Lisboa			2010/2011	1		Biologia e Geologia (520)		
Aveiro	Águeda							

Figure 5.26 - The survey dataset can be shared in a DRN by embedding the Excel file on one of its pages. The spreadsheet can be opened with just one mouse click

5.7 Developing the website OneNote in Research

I launched in September 2015 together with Luís Barbeiro the website OneNote in Research (http://onenoteinresearch.com), in Portuguese and English languages, to share with the research community the lessons learned in managing the entire qualitative research process based on the challenges of this thesis and the project.

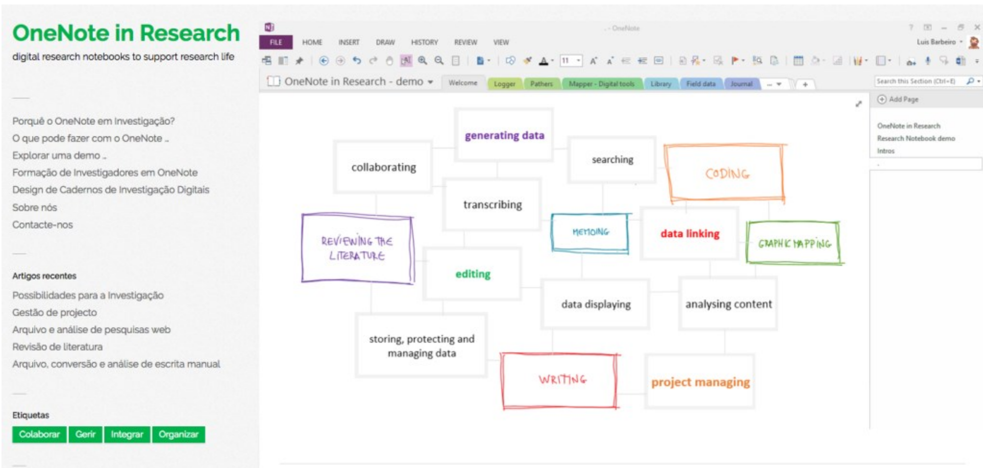


Figure 5.27 – Homepage of OneNote in Research

The website features an open access notebook template of what we called Digital Research Notebook (DRN), that can be downloaded by any researcher and adapted to her needs and research project. Several examples of application of the DRN are displayed on the website, for collaboration, reviewing the literature, generating data, transcribing, writing, project managing, coding, graphic mapping, memoing, editing, searching, analysing content, data linking and displaying, storing, protecting and managing data. An online professional development programme was also being planned in 2017.

An invitation of a peer-reviewed case study to be included in SAGE Research Methods in Education was made by SAGE in November 2015, accepted by the authors and published in January 2017, with real examples from this research.

A snapshot of the DRN used in this research is also available online, in the research section of the website http://laboratorioescolares.net.

5.8 Coda

In this chapter, besides presenting the overall methodological choices made for this study, I have shown the application of a new concept, the Digital Research Notebook to my own research project. I have tried to show you some concrete dilemmas in a research project and how DRNs can help solve some of them. Looking beyond the technical details and paraphernalia, the impact of DRNs I most value in my research is that it made many of activities more productive and insightful, while fostering in practice my values of doing research in a collaborative, participatory, grounded, reflective and open way.

My vision of an open Science is one that goes beyond communicating and sharing only the research results. Making accessible the processes of research is fundamental to the quality, ethics and responsibility of Research in Society. I believe that Digital Research Notebooks can be a way of achieving these ends.

6. Science Learning Studios in activity – Case studies

In the following chapter, 5 case studies will be presented. The first, a case study with an ethnographic approach of year 12 open inquiry Science, took place in 2010 in one school in the Alcobaça region, following one class across scientific subjects in year 12, particularly Project Area (AP) lessons taught by a Science teacher. The second was concerned with the development of the concept of Pedagogical Graphic Novel and the application of the SLS activity analysis methodology, working with a Science teacher and a year 10 class in a school in the Lisbon area. The third, taking place in a school in the Oporto region, tried to understand in detail how the elements of the Science Learning Studio were viewed by a teacher, to later inform the design of a survey, presented in chapter 7. The fourth and fifth case studies, taking place in two schools in the Algarve and Setubal regions, were concerned in understanding the organisation and management aspects of the Science Learning Studio, to later develop a Science Learning Studio organisation and management model, a professional development course and a website, presented in chapter 8.

6.1 Case study 1 – An ethnographic approach to year 12 open inquiry Science

Science classes in Portugal take place in both regular classrooms and laboratories. This separation of spaces, inherited from the first "Liceus", is aligned with a separation of teaching activities, one essentially theoretical, the other more practical. The materialisation of this separation can be seen in several aspects of daily school practice, such as:

1. Specific textbooks for each of the components;
2. Labels that reinforce this separation (adding a T to the theory slot and a P to the practice slot);
3. Attributed schedules (theory classes with two slots of 90 minutes per week, practical classes with one slot of 135 minutes per week);
4. Attributed spaces (regular classrooms for the first, laboratories for the later);
5. Class organisation (whole class for the first, half class for the later).

Since the reform of 2003, the same teacher had both components in his schedule, a contrast with the previous separation of subjects: theory and practical components had a subject of its own, for example Biology and Biology's Laboratorial Techniques, with different teachers and eventually students for each.

In the school year 2006/07, following the reform of 2003, the subject "Área de Projecto" (Project Area, AP) was introduced in year 12, to later be removed in 2011/12. The policy discourse positioned this subject as the ideal space and time for students to develop personal and social responsibility, participation, citizenship and a career orientation, giving emphasis to links between school and the community (Ministério da Educação, 2006). One of the practicalities of the lack of a teaching curriculum in this subject, was on one side, the attribution of Science teachers to classes that have chosen scientific subjects in year 12, and on the other, that at least part of the projects undertaken would be Science-related, some driven by students' interests, others by teachers' interests or a mix of both.

In this section, data from one case study with an ethnographic approach collected in the school year 2009/2010 will help to explore research question 2 on an open inquiry subject related to Science (AP), describing some of the teaching and learning activities that are taking place in the SLS. The ethnographic stance at an early stage of the research project created opportunities for richer, deeper understandings of these activities. The data was collected in theoretical, practical and project Science classes across an 11 weeks' period in the second term in one school. These included field notes, audio recordings of teacher-students' interactions, unstructured interviews with teachers and students, photos, documents and records of students' work.

6.1.1 Revisiting the case study approach

The option for a case study approach was related to its potential to provide opportunities for rich, descriptive data, allowing complexity, depth and theorization about the phenomenon (Merriam, 1998).

Case study is not sampling research (Stake, 1995), and this study was not concerned with strong representation of other cases. One school was chosen to maximise opportunities to learn from the lessons. This school was a private institution located in a village, with students in the upper quartile, with the same (Science) teacher teaching the three modes of Science lessons. Access was also considered, as previous involvement with this schools made access to the Science department easier.

Another reason for selecting a case study approach was that it would enable full involvement in the case and "catch the close-up reality and thick description of participants' lived experiences of, thoughts about and feeling for, a situation" (Cohen, et al., 2005, p. 182). This method is usually adopted when researchers have little control of the events, and when the focus is contemporary phenomena within real life contexts (Stake, 1995).

Observations were carried without participation in an established role. I presented myself to both teachers and students as a researcher. Presence in theory lessons was mostly as an observer, with occasional conversations in practical lessons and increased participation in project lessons, as the dynamics of interaction with the class developed over time. I would usually sit in the last row of tables in the first two lessons (T and P), and in the front of the class, next to the teacher, in the later (AP). My participation in the project classes was mostly by giving some ideas to some of the projects, such as using a software for creating a 3D model of the school, contacting some people or institutions that could help, suggesting alternatives to some steps of experiments, providing sources to obtain more information or for example, sending students' some photos of their practical activities so that they could include these in their reports. Out of the classroom, I would usually accompany teachers to the teachers' room, engaging in diverse conversations.

Several techniques used by social researchers are concerned with establishing the credibility of the research and its knowledge claims, such as prolonged engagement, persistent observation, peer debriefing, progressive subjectivity, and member checks (Guba & Lincoln, 1989). The concerns with credibility led to design the study so that I could stay as long as possible in school (11 weeks), assuring persistent observation (across all Science related components of the curriculum of one year 12 class, with 7 hours of classes per week), and debriefing (during lessons or after it).

6.1.2 School, teacher and class

The data collection took place in "Externato Cooperativo da Benedita" (Cooperative School of Benedita), near Alcobaça (ECB). The class was chosen considering the teacher's availability for the study. The head teacher was contacted, and a presentation was made with the goals and details of the study, asking for permission to present it to the Science department. A presentation was arranged in ECB, information sheets and consent forms were distributed and signed, and considering the schedules of the available teachers, one class was chosen.

The schedule of weekly observation was Monday (16:15-18:30), with a Biology practical lesson, Wednesday (14:30-16:00), with a Biology theoretical lesson and Thursday (14:30-17:45), with AP.

The school was 100 km far from where I was based, which was time-consuming and expensive to travel to (one hour and a half to two hours each way by car, considering traffic, plus highway tolls).

Figure 6.1 - Location of the school, in red (Google Maps, 2010)

Data collected in the school year 2009/2010 involved field notes taken during classroom and out-of-classroom observations, photos and short videos of activities, spaces and products of students' work, either taken by the myself or by students and teachers, document collection, consisting of reports and other documents made by students, and audio recordings of interactions inside and outside the classroom. In retrospective, if I had developed the concept of Pedagogical Graphic Novel from the beginning, my work would have been much easier.

"Externato Cooperativo da Benedita"

The first visit to "Externato Cooperativo da Benedita" was in July 2008, due to my involvement in the team that designed the model for the secondary schools' Science spaces. ECB, as a private school, was not included in the ongoing national rebuilding initiative, but the Physics and Chemistry group felt the need to redesign some of its laboratories, built almost two decades ago. In a serendipitous way, the Head of the Physics and Chemistry Group and the Head of Resources approached Prof. Vitor Duarte Teodoro (FCT-UNL, that lead the design team), due to its involvement in Science Education initiatives in general, not knowing at the time about of his team's involvement in the rebuilding initiative.

ECB had an attractive feel, with a calm atmosphere despite its crowdedness. It likes to call itself the most public of the private schools, as it does not require any students' fees and student access is only defined, as in an ordinary public school, based on the address of the families at the time of enrolment. A case of community leadership, the school was founded in 1964 through the creation of "Instituto de Nossa Senhora da Encarnação" (Institute our Lady of Incarnation), due to the lack of a public school and the financial difficulties of the population to send their children to far away schools. Gonçalves Sapinho, one of the initial leaders, was the head teacher for many years, and later mayor of the municipality of Alcobaça, where Benedita is located. He gives his name to the cultural centre built in the school grounds, with a performance hall, audio studio, library and multi-uses area, which can be used by both the school and the entire community. Several events such as the schools' cultural week or the school yearbook were instruments to show the activities being done by its people to the community. There is a culture of partnerships (one of the strategic goals of the school), with teachers and students developing several projects out of school, with community institutions (primary schools, associations) or universities. Since 2008, the school is recognised by the Portuguese Association for Quality with the level "Committed to Excellence", something not usually seen in public schools. It is also in the upper quartile of the national schools ranking, which ranks schools per year 12 grades and national exams' results.

The school was located in the hearth of the village of Benedita, surrounded by one high school, a primary school, the church, a day centre for young children and the elderly, a football field from the village team, and a commercial area. The industrial area is located at a walking distance. It has 113 teachers, with close to 50% teaching for about 10-20 years. It has 1400 students, mostly from the village or the surrounding villages, with two-thirds expecting to follow a higher education degree (ECB, 2009).

Figure 6.2 – ECB location and surrounding area (left) and school entrance (right).

Besides observing lessons, I spent some time in the school library (where students from the observed class where usually found) and in the teachers' room and in a restaurant, close to the school during lunch time, talking to several Science teachers. Conversations with members of staff (laboratory technicians, the head teacher's secretary) were also common.

The teacher, Maria

Maria has been a teacher in ECB since 1993. She took her degree in Biology in the University of Aveiro, and her sister was a researcher in the same area in the University of Algarve. It was her fourth-year teaching Biology and AP in year 12, as she accompanied the curriculum reform right from the start. She has won several prizes with her students, such as "Ciencia en Acción" 2006 (Science in Action) or Futur Energia (Future Energy), and she kept assisting several projects still running, such as the young reporters for the environment, two individual Science projects out of her school assigned hours, and Science activities for disabled children in a specialised centre near Benedita. She very much valued the participation of students in Science contests and projects.

She was the class tutor, and also the Biology teacher, having taught most of the students in the previous secondary level' years. The head teacher decided to assign her to the AP subject as she was a specialist subject teacher (a choice that was endorsed by the policy documents for the subject).

Class

The class had 16 students, 13 girls and 3 boys. This class was considered by Maria one of the best classes in school. High grades across all subjects were common, and behaviour was good. All students except two aspired to pursue a higher education degree, mostly health related (nutrition, medicine, biomedical engineering, pharmacy) and on biology, speech therapy or environmental studies. Two of the boys referred in a survey in the beginning of the school year mentioned that they were thinking about pursuing a military career. Most the parents had a secondary level or lower degree and had commerce or industry related jobs.

6.1.3 Vignettes and analysis

The huge amount of data gathered in the ethnographic approach demanded pragmatic choices to be made from the range of approaches available to the analysis of qualitative data. The goal of this research method was to follow teachers and students' in diverse teaching and learning activities taking place in open inquiry Science lessons, involving at least in part the SLS but not limited to it. Four vignettes will be presented in the current section, as a snapshot of the teaching and learning activities observed in these lessons.

Vignette 1

As I enter prep room 37A, I see two groups of students from the Physalis and Lethal inspiration projects. An air quality measurement kit has just arrived for the second group and students are unpacking it in the central bench. At the same time, José and Rui, from the first group, are putting soil in two vases, so that they can plant some Physalis plants. After this, they start ripping some old newspapers, putting them in a container, and crushing some of the fruits they bought from the local market in a tumbler. Sepals of the plant are already prepared, and a protocol for making recycled paper is on the table, provided by the Biology teacher.

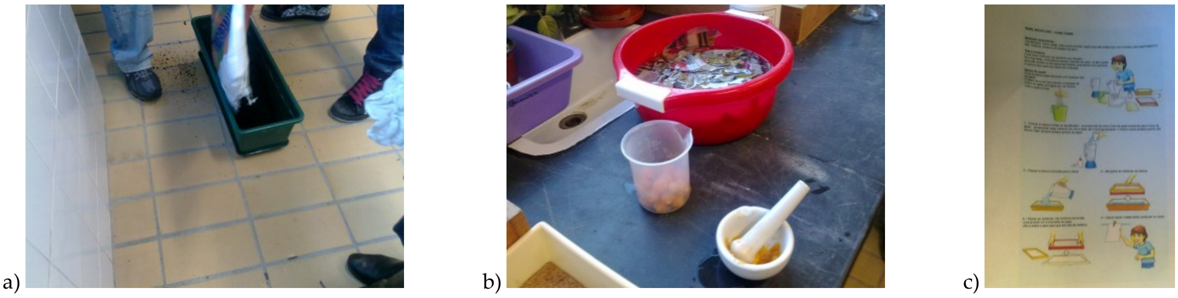


Figure 6.3 – a) Student filling in a vase with soil to plant Physalis; b) Preparation of recycled paper made with Physalis sepals; c) Protocol provided by the Biology teacher on how to prepare recycled paper.

Vignette 2

> The project was the teacher's idea, but we like challenges (An AP student)

One of the Science teachers from ECB, teaching Biology to a year 12 class, organised a seminar with two researchers from "Instituto Superior Técnico" (IST), one higher education institution with a partnership with the school. She invited all year 12 classes with Science related subjects, and colleagues from the Biology and Geology group of which she is head of the group. The theme of the seminar is stem cells research, included in the curriculum, and the researchers were invited to talk about the work their group is developing in the optimisation of the production of these types of cells. This seminar took place in the cultural centre, in one of the seminars room, and teachers and students were present, including Maria. This was on a Friday, 2.30 pm, the same time Maria had AP classes with 12A. Some of her students are present, most from the group of the "Aqua furonis" project, and one of the boys is filming. Maria stays for the first hour, as she must meet the other groups that are working on their projects either in school or in the surrounding area.

I stay a little bit longer, and later meet Rui, one of the students, working independently in his project Physalis in the prep room referred in the beginning. Mrs Audete, one of the laboratory technicians, occasionally checks the room, but does not intervene in his work. I take the opportunity to talk a little with him about his project, and especially clarify where did the idea come from and try to understand what he has been doing lately concerning the project. He is checking the reactants that he prepared earlier with his group partner (José, missing classes for almost a week due to illness) in the chemistry's group fume cupboard and reading the protocol he obtained from old ECB students that also had a project related to this fruit (concerned with tea production). His group wants to chemically characterise the Physalis species they got from the local market, and this will include among others, the determination of its iron levels. After checking if all the reactants are present (he opens the reactants cupboard), he marks in the protocol those that are missing, to later get these either through Maria or "Escola Superior de Biotecnologia" (Biotechnology School) of the Portuguese Catholic University (ESB), 20 km away from the school in Caldas da Rainha. He does the same with the required equipment and gathers what he could find in the central bench. Next week, they will be going to ESB's laboratories in the town of Caldas da Rainha to use the spectrophotometer and get some help from staff, where one of Maria's ex-students is a researcher.

After this verification, he puts some water on the vases in one of the benches where he is growing more physalis. He still has doubts about the species of physalis he is dealing with. A search on google scholar provided him with a paper about a similar research but he still does not know how to verify the species in question. He asks me if I want to go with him to check the plants they have been growing in one of the small spaces filled with land, close to the school's entrance. They wanted to grow them close to the football field, where there is more space and land, but the head teacher asked them to use this space instead. They used a plastic to cover the plants and Rui bought some sticks he got near his place and wanted to check if the plants were growing well. Some of the plants leaves were eaten, "probably snails" and he tries to see if he can find the "plant eaters". He does not find any, and satisfied with the state of the plantation, covers it again.

Figure 6.4 - Covered physalis plantation in the school grounds

I ask him why they are doing the plantation, and he replies, “we are going to try and sell cakes made with the fruits”. I ask him where this Physalis project idea came from. When we were in the preparation room, I asked him about his interests and he told me he liked animals very much but had already put Veterinary on the side due to his low grades and was thinking about pursuing Animal Biology. In the beginning of the school year, he was considering a military career, as I later found out from a students’ survey provided by Maria. I was intrigued with this selection of the theme, as animals, not plants, were one of his main interests, to which he replied “the project was the teachers’ idea, but we like challenges”. I had been present to one lesson in the first term, when his group was on the planning stage of their project, and work was done mainly inside the classroom, searching on the Web and preparing the worksheets provided by Maria to support this phase. I did not actually get the sense they owned the project. Most of the time they would be talking about different matters. The initial idea of determining the effects of the plants on diabetes and the use of rats to make the experiments was more aligned with at least Rui’s interests, but as this situation became unpractical, this could explain the lack of enthusiasm of the group.

As alternatives to the initial plan were chosen, such as the preparation of recycled paper or a cake made with physalis juice, I observed a positive change in attitude, particularly in José. Contrasting with the first lesson I was in on the 1st term, he would be getting the materials, preparing the paper and the fruits, and bringing the products (paper produced with some tips from another teacher from the eco-schools’ project and cake that was prepared in the school canteen with support from the staff) to show to the teacher and the class.

Vignette 3

The use of social and institutional networks is common in AP. Maria in particular makes great use of this to answer questions and solve problems (for example, asking for some consulting work to her sister that is a researcher) and to provide opportunities and ideas to their students (with ESB and her former student which became a researcher, with the participation in contests and larger projects). In the beginning of a Biology class, this connectedness could be seen from the description of the tasks she had undertaken concerning the projects, and the people to which she had to talk with. The use of students' social networks also happens, becoming an important source of information, knowledge, skills and resources. For example, in the project Recycling on the move, students used the garage of one of the parents of a group member and his knowledge to develop their work.

ECB's cultural week was to take place in May. This would be a moment for the school to show some of its activities to the community. It was a novelty this year, a way of aligning different activities (week of the languages, Science week) in a larger event. Some students would be responsible for part of the activities, and Science subjects and AP projects would have a space of their own in this event. This is something that contrasts with the standardised forms required in theoretical and practical lessons.

Participation in contests and larger projects, especially in AP, was quite common in ECB's classes. The class, for example, was involved in TWIST, and one of the projects was to compete in "Rock in Rio Escola Solar". Even in Biology, Maria suggested several competitions, such as the Biotechnology Olympics or the DNA day, to which several students adhered.

Vignette 4

As I enter the computer lab (the assigned classroom for AP), I find Andreia, which was several years ago one of Maria's students, providing some advice to the students' projects. She is a researcher in ESB and her expertise was requested by Maria, as it could be helpful for at least two of the projects: Physalis and Experimental Challenge. Both projects are concerned with the antibiotic properties of several plants (including physalis, coriander, garlic) in *E. coli*, comparing these to know antibiotics such as ampicillin.

Andreia suggests the Kirby Bauer technique, using the Mueller-Hinton agar, and the protocol will be executed in ESB by students with the help of the staff. Margarida, one of the members of the group of the Experimental Challenge' project, uses the board together with Andreia to represent several steps of the protocol. They will also be testing the physalis' properties for José and Rui's group. Lara, also from the group, after participating in the discussion of changes to be made to the protocol, posts to the Ciência Viva forum a question to the group moderator as the group is concerned that the changes made can take them out from the contest. Ciência Viva is a national agency with a network of Science centres that among other things, organises contests and provides resources for Science activities in schools. The Experimental Challenge (with the theme chosen by the group being "And when antibiotics don't work?" in the modality Scientific documentary) is one of their proposals for the present school year, and they are providing kits of equipment and online support to the participating groups of students.

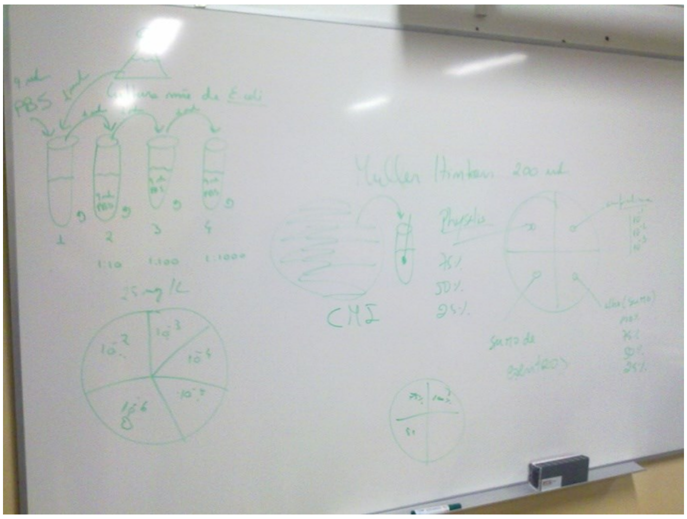


Figure 6.5 - Planning of the experimental procedure in the whiteboard with an invited scientist

A week later, in the same class, I heard the news. I asked Lara if she had any answer and she told me with a disappointed look, "We're out". The person responsible for supporting schools in the project replied them the next day, informing that due to the contest regulations, the change of protocol puts them out of competition.

However, the group did not give up on the research project. Next month (even though they receive the kit that was sent anyway by Ciência Viva, and that Maria would use in a Biology Practical lesson later in the term), the group got the bus to ESB, and following the suggestion made by Andreia, used the Kirby-Bauer technique in the ESB's laboratories, with support from the staff and the institution (that provided the growing medium, specific equipment and of course, the space). This institutional support, despite not offering the opportunity to win a prize and see its work published on the project website, allowed a series of activities, such as the negotiation of the protocol among the group and the "scientist" and within the contexts in which both had to work.

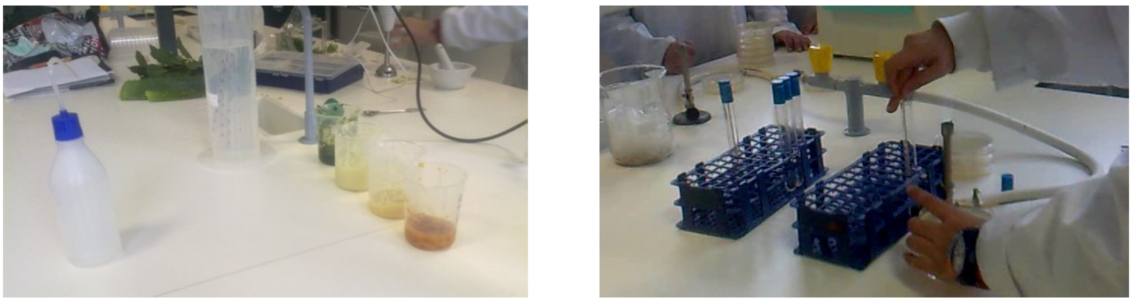


Figure 6.6 – a) Preparation of the Kirby-Bauer technique; b) Inoculation of Petri dishes with E. Coli

In the same visit, students from the Physalis group engaged, with the support of the lab staff, with a professional spectrophotometer, to analyse the content of the physalis fruit for their report.

Figure 6.7 – Students in ESB using the spectrophotometer

6.2 Case study 2 – Analysing a practical lesson in the Science Learning Studio

Case study 2, as mentioned in section 4.1, supported the development of an activity analysis methodology using Pedagogical Graphic Novels. To develop the concept of Pedagogical Graphic Novel, 8 lessons were observed and captured through various means (video and audio recordings, scanning of documents, photos, field notes). In this section I will present an analysis of a laboratory activity using the activity analysis methodology, applied to the Pedagogical Graphic Novel made in collaboration with the student doing the capture, the teacher and myself.

6.2.1 School, teacher and class

The school was in the Lisbon region, on its outskirts, and was inaugurated in 1982. It was a 3 × 3 blocks pavilion school and was intervened by Parque Escolar in phase 2, 2008-2009. The modernised school was delivered in October 2010.

The Physics and Chemistry teacher was an experienced secondary Science teacher in the school, accompanying the transition from the old to the rebuilt school. Acting as head of facilities in previous years, I knew her from the accompanying process of schools done during the consultancy work on developing the new model of Science spaces for Parque Escolar. Me and Prof. Vitor Teodoro made several visits to the school and supported this teacher as head of facilities, suggesting some solutions to everyday problems, talking to the lab technician and observing some lessons.

The example provided in this case study using the analysis methodology developed in this thesis was made with the collaboration of a year 10 class. The documentation of activity, done in 2015 by one of the students with my support, was also used after the documented lesson, to support students in reflecting about the activity and eventually achieving some of the goals established for it. My formal analysis was only made more than a year after the observed lesson.

6.2.2 Applying the activity analysis methodology to a Science lesson

The Pedagogical Graphic Novel constitutes the documentation of the lesson to support analysis and reflection on the learning activity. In the following section, the activity will be presented, divided into tasks and analysed using the analysis methodology developed in section 4.6.

General details of the lesson

Laboratory activity 1.3: Relative density of metals

Physics and Chemistry year 10

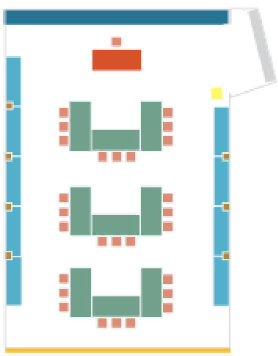
Time: 2015.11.30 08:25-11:00 (135 minutes + break)

Place: Laboratory A

Class: 5 groups of 3 students each (15 students in total, first half-class)

Summary: Laboratory activity 1.3. Group presentation and discussion of results.

Bench arrangement:

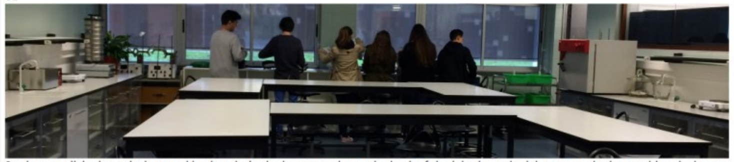


Activity: Determination of the specific gravity of metals using a pycnometer

The activity is one of the listed laboratory activities in the year 10 Physics and Chemistry curriculum, Lab activity number 1.3 – Determination of the specific gravity of metals using a pycnometer. In the following pages, I present the Pedagogical Graphic Novel, followed by its analysis.

Task A – Planning of the practical work

01

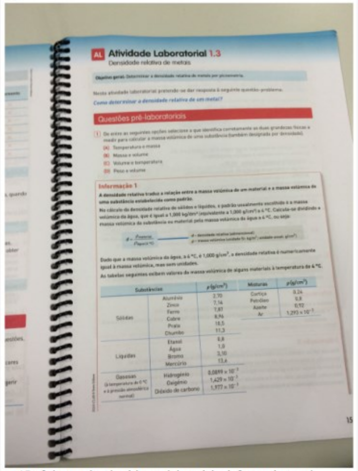


Students walk in, leave jackets and backpacks in the honeycombs on the back of the lab, dress the lab coats and take graphic calculators, pens, pencils, textbooks and journals for the working benches.

02

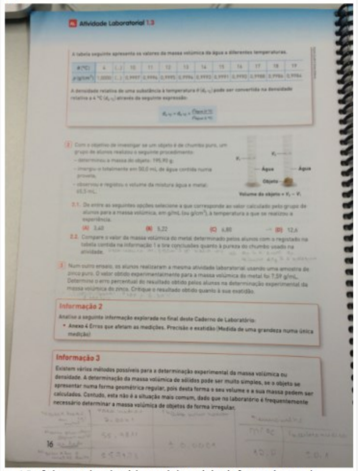
The teacher asks students in groups to, in 5 minutes, review the pre-report of the lab activity 1.3. She then reviews with the large group, questioning individual students, the goal of the activity (determination of the density of a metal), the procedure, the reasons for some of the steps of the procedure, the materials used and some necessary calculations.

03



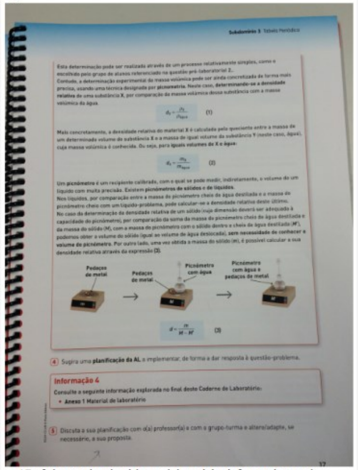
p. 15 of the textbook with pre-lab activity information and questions

04



p. 16 of the textbook with pre-lab activity information and questions

05



p. 17 of the textbook with pre-lab activity information and questions

06

Each group discusses some of the pre-lab activity information and questions in the textbook

07

From the trolley, in the lab front, with the lab activity material organised in trays for each group, she shows some of its contents to the large group, asking questions about their function, safety and risks (e.g the pycnometer) and sometimes making some demonstrations, with the help of individual students.

08

In the whiteboard, one student draws a table to organise the observation data and facilitate the calculations of the density of the metal.

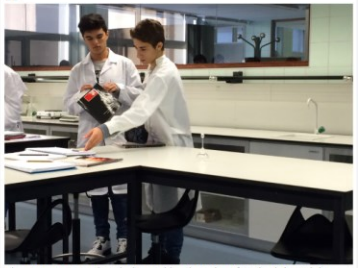
09

The teacher reviews with the large group the organisation of the table, correcting some aspects in the whiteboard (e.g. representation of the variable Temperature)

10

The teacher uses direct instruction to demonstrate the use of the thermometer and on how to indentify the uncertainty associated to each measuring instrument (pycnometer, thermometer, digital scale).

11



The groups organise their working benches for the lab activity, placing some of their stuff in the backpacks in the honeycombs and lowering the stools, placing them under the benches.

Task B – Practical work

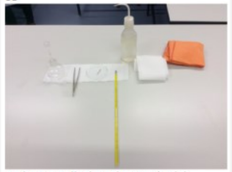
01

Each group brings one tray from the trolley parked in the lab front to their working benches.

02

One of the students takes 5 samples of metal for the groups to determine its density

03



Each group displays the require lab material on the working bench, over a strip of absorbent paper: 1 Pycnometer, 1 water bottle (distilled), 1 Petri dish, 1 metal sample, 1 thermometer, 1 Pasteur pippete (brought later on by one student from the prep room), absorbent paper, 1 cloth. Two shared digital scales are on the side benches.

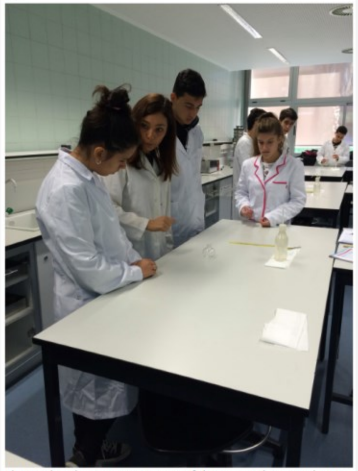
04

Each group measure the mass of its empty pycnometer. All measurements are made three times (e.g. 28.79 g)...

05

... later measuring its mass full of distilled water, again three times (e.g. 150.70 g)

06

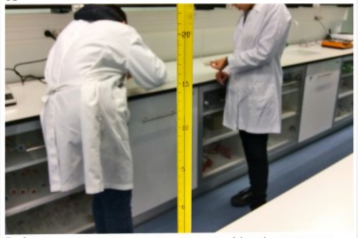


The teacher demonstrates to one of the groups the procedure to fill and cover the pycnometer.

07

Each group partially fills the pycnometer with distilled water, slowly making the liquid flow through its inner wall to avoid the formation of air bubbles.

08

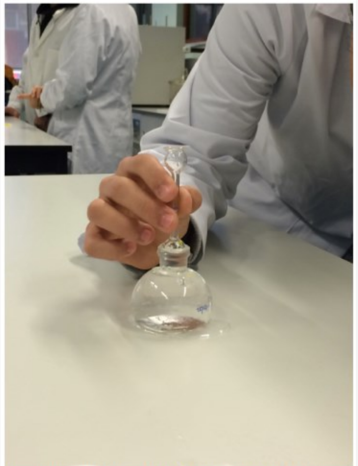


Each group measures room temperature with a thermometer, registring three measures (e.g. 20.1 °C) ...

09

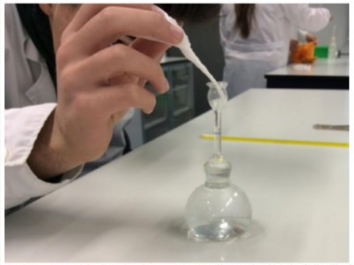
... and the temperature inside the partial filled pycnometer.

10



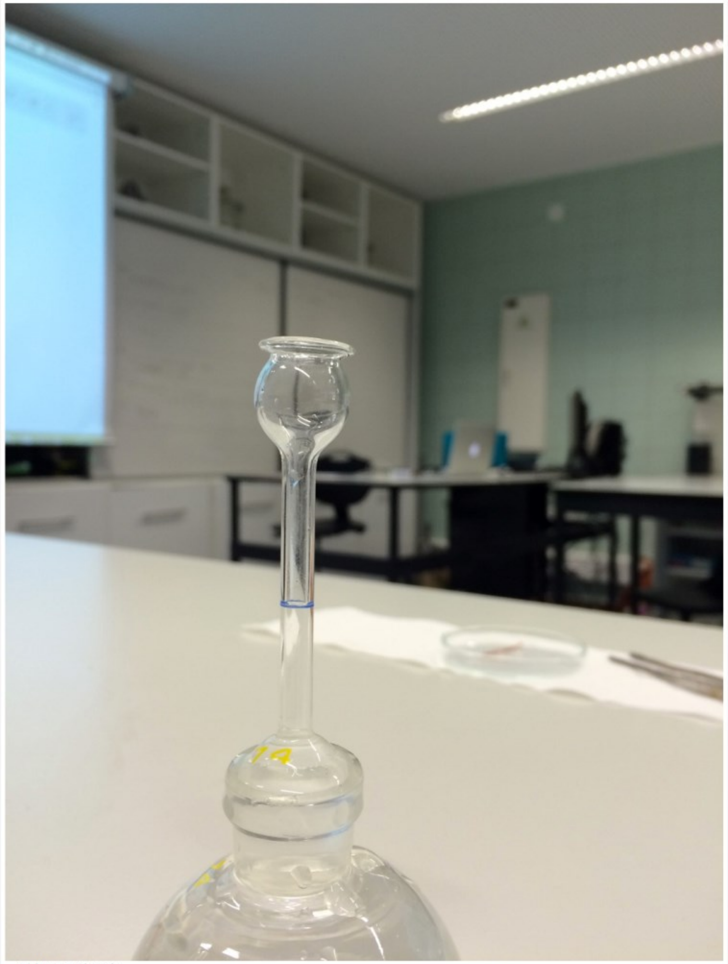
Each group then fills the pycnometer until full capacity with distilled water using a Pasteur pippete, covering it in na horizontal movement related to the face of the nozzle, followed by a vertical movement that forces all the liquid to its interior.

11



Each group, with the aborbent paper, adjusts the level of distilled water, absorbing the excess water...

12



... to the 100 ml mark.

13

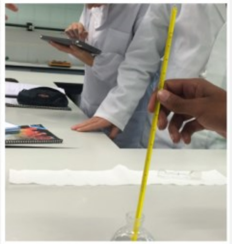
Each group measures the mass of the pyconometer full of distilled water, registring three measurements (e.g. 150.70 g)

14

Each group measures then the mass of the full pycnometer and the metal sample on the side (three measurements)

Each group measures then the mass of the full pycnometer with the metal on the inside (three measurements) (e.g 151.04 g).

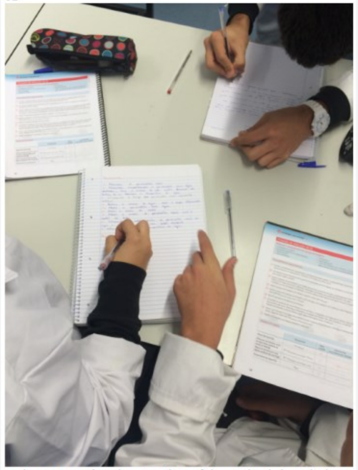
15



Room temperature is again measured by each in the end of the activity and the three measurements are registred in the journal.

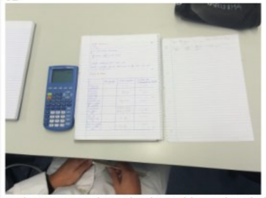
Task C – Data analysis

01



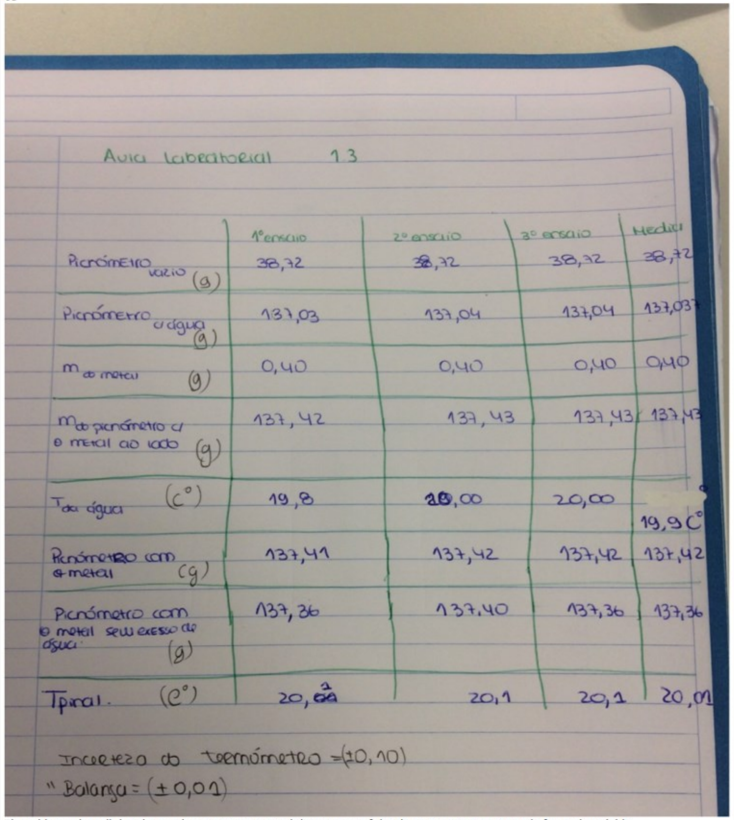
Each group rewrites the procedure of the textbook, introducing the changes made during the lab activity.

02



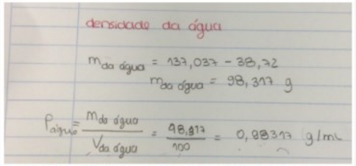
Each group completes the data tables and analysis data, with the help of a graphic calculator. The teacher circulates in the lab, verifying calculations and results and providing feedback.

03



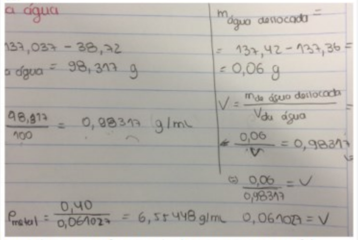
The tables gather all the observed measurements, and the average of the three measurements made for each variable.

04



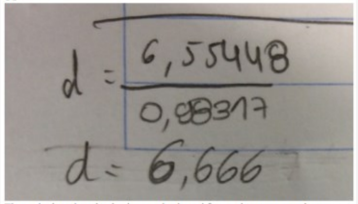
A detail of the calculation of the density of distilled water (e.g. 0.98317 g/ml)

05



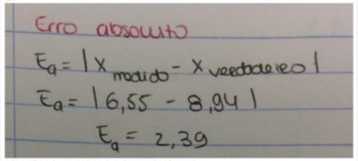
From the average of mass and volume measurements of the distilled water displaced by the metal inside the pycnometer, the density of the metal is calculated (e.g. 6.55448 g/ml)

06



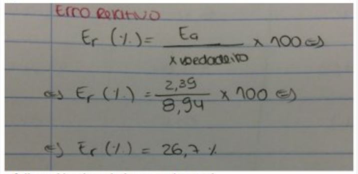
The relative density is then calculated from the two previous obtained values.

07



The absolute error is also calculated...

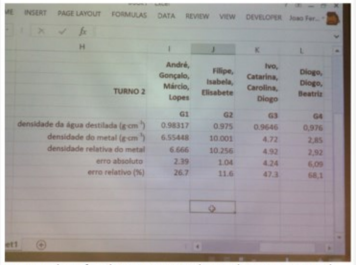
08



...followed by the relative error (26.7 %)

Task D – Presentation and discussion

01



TURNO 2	André, Gonçalo, Márcio, Lopes	Filipe, Isabela, Elisabete	Ivo, Catarina, Carolina, Diogo	Diogo, Diogo, Beatriz
	G1	G2	G3	G4
densidade da água destilada ($g \cdot cm^{-3}$)	0.98317	0.975	0.9646	0,976
densidade do metal ($g \cdot cm^{-3}$)	6.55448	10.001	4.72	2,85
densidade relativa do metal	6.666	10.256	4.92	2,92
erro absoluto	2.39	1.04	4.24	6,09
erro relativo (%)	26.7	11.6	47.3	68,1

One member of each group goes to the teacher computer and writes the results in a table on a spreadsheet, projected in the teaching wall. The teacher instructs on the correct use of significant figures. She then questins the students on the reasons for the large discrepancy of results obtained in the lab activity and the literature values of the known metal. The teacher reminds students to clarify that issue in the group lab report.

02

Each group places the material in the trays and cleans the benches with the cloth

03

The trays are stored in the trolley.

THE END

The steps taken here to analyse this activity are the following:

1. **Define and decompose the activity into units of analysis** (in the case, only into tasks);
2. **Define the leading scale domain of each unit of analysis and the transitions between domains** (the leading domain, as tasks can be somewhat messy and engage multiple domains);
3. **Analyse the motive, programme and goal of each task** (either from the curriculum or from the documented activity).

Definition and decomposition of the learning activity into tasks

From the observation of the lesson, the following tasks were identified:

1. Planning of the practical work;
2. Practical work;
3. Data analysis;
4. Discussion.

Definition of the leading scale domains of the learning tasks and the transition between domains

The leading scale domains of the learning tasks are represented in the following figure, with the time dimension not representing identical time intervals but only the overall progression:

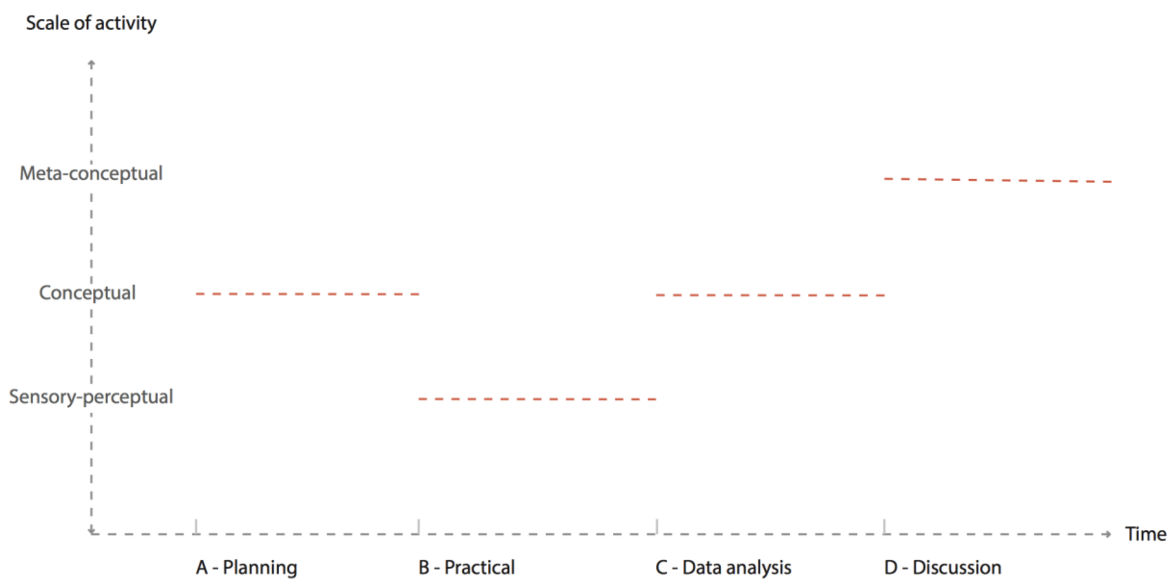


Figure 6.8 – Tasks and evolution of the scale domain of activity over time

This distribution was made considering the nature of the tasks performed by students. During the planning task, the leading scale domain of actions was mostly conceptual, with occasional manipulation of objects and equipment and some references to meta-conceptual aspects such as accuracy of measurements. During the practical work task, the leading scale domain of actions was mostly sensory-perceptual, with students engaging in manipulation of equipment following a protocol. In the data analysis task, again the leading scale domain of actions was mostly conceptual, concerned with calculations and manipulation of concepts such as specific gravity, density, average, error, etc. In the final discussion task, the leading scale domain of actions was mostly meta-conceptual, concerned with aspects of accuracy, precision and experimental errors.

Description of the motive, programme and goals of each task

The goals established in the Physics and Chemistry Curriculum in year 10, both specific to the Activity or that develop broader goals, were organised into the three scale domains:

Table 6.1 – Specific and general goals of the activity, according to scale domains:

Type	Sensory-perceptual	Conceptual	Meta-conceptual
Specific goals	(Interpret) and use a protocol that permits the determination of the specific gravity of a metal using a pycnometer Identify the specific gravity as a physical property of substances	Define specific gravity and relate it with density Determine the specific gravity of the metal. Interpret the meaning of the obtained value for the specific gravity of the metal	Determine the error (%) of the obtained value for the specific gravity of the metal and relate it with the accuracy of the value Describe the errors that might affect the obtained value
General goals	Identify lab material and equipment and use it correctly, following safety rules and the given instructions Identify measuring devices, analogical and digital, its interval and the margin of error of the measurement Make measurements using lab material, analogical or digital, or automatic data acquisition devices Represent a set of measurements in a table of records, together with the experimental uncertainty related to the measurement done on the measuring instrument	Identify the goal of the practical work Identify the theoretical domain on which the protocol of the practical work is based upon, and associated safety rules Interpret and follow a protocol Design a table of records to register data, adequate to the protocol Use rules to identify significant figures	Distinguish between random and systematic errors Describe the value of a physical quantity in one direct measurement, considering the experimental uncertainty related to the measurement done on the measuring instrument Associate the accuracy of a value to its proximity to a true value and to systematic errors, relating it to the error (%) Generalise interpretations based on experimental results to explain phenomena that have the same theoretical assumptions Identify errors that can justify low precision and low accuracy of the obtained value

Type	Sensory-perceptual	Conceptual	Meta-conceptual
			Determine the error (%) of a value obtained in an experiment when there is a true value

Following the decomposition of the activity into tasks, the specific and general goals were organised into scale domains in the following table:

Table 6.2 – Tasks and respective specific and general goals across scale domains

Task	Sensory-perceptual	Conceptual	Meta-conceptual
Task A – Planning of the practical work	Identify lab material and equipment and use it correctly, following safety rules and the given instructions	Define specific gravity and relate it with density Identify the goal of the practical work Identify the theoretical domain on which the protocol of the practical work is based upon, and associated safety rules Interpret and follow a protocol Design a table of records to register data, adequate to the protocol Use rules to identify significant figures	-
Task B – Practical work	(Interpret) and use a protocol that permits the determination of the specific gravity of a metal by pycnometry Identify the specific gravity as a physical property of substances Identify lab material and equipment and use it correctly, following safety rules and the given instructions Identify measuring devices, analogical and digital, its interval and the margin of error of the measurement Make measurements using lab material, analogical or digital, or automatic data acquisition devices. Represent a set of measurements in a table of records, together with the experimental uncertainty related to the measurement done on the measuring instrument	-	
Task C – Data analysis	-	Determine the specific gravity of the metal	-

Task	Sensory-perceptual	Conceptual	Meta-conceptual
		Interpret the meaning of the obtained value for the specific gravity of the metal Use rules to identify significant figures	
Task D - Discussion	-	-	Determine the error (%) of the obtained value for the specific gravity of the metal and relate it with the accuracy of the value Describe the errors that might affect the obtained value Distinguish between random and systematic errors Describe the value of a physical quantity in one direct measurement, considering the experimental uncertainty related to the measurement done on the measuring instrument. Associate the accuracy of a value to its proximity to a true value and to systematic errors, relating it to the error (%). Generalise interpretations based on experimental results to explain phenomena that have the same theoretical assumptions Identify errors that can justify low precision and low accuracy of the obtained value. Determine the error (%) of a value obtained in an experiment when there is a true value

Concerning motives, following the decomposition of the activity into tasks, actions that related to basic psychological needs of autonomy, competence and relatedness were organised into the following table.

Table 6.3 – Tasks and addressing of autonomy, competence and relatedness needs

Task	Autonomy	Competence	Relatedness
Task A – Planning of the practical work	Group autonomy in preparing the practical activity Student-led demonstration to the large group of a certain procedure	Correct demonstration by a student after teacher scaffolding Conclusion of the table of records and sharing with the entire class on the whiteboard	Group work with significant others, student-teacher quality of relationship

Task	Autonomy	Competence	Relatedness
Task B – Practical work	Group autonomy in leading the practical work Ownership of experimental data obtained	Correct following of the procedure with teacher support when required	Group work with significant others, student-teacher quality of relationship
Task C – Data analysis	Group autonomy in leading the data analysis	Correct filling of the table of records and calculation of required values	Group work with significant others, student-teacher quality of relationship
Task D - Discussion		Domain of the concepts of accuracy and precision	Group work with significant others, student-teacher quality of relationship Sharing of results in the whiteboard and of possible experimental errors by the groups

Concerning the programmes, following the decomposition of the activity into tasks, actions that related to non-iterative and iterative programs were organised into the following table.

Table 6.4 – Tasks and non-iterative and iterative programs used

Task	Non-iterative programme	Iterative programme
Task A – Planning of the practical work	Reading and solving in group of pre-lab activity worksheet, with observation of illustrations of equipment used in practical work and textual and schematic description of procedure in pre-lab activity worksheet Reading and solving in group of pre-lab activity worksheet with information on identification of materials, definition of density and formulas, comparison of calculated and reference density tables Reading and solving in group of pre-lab activity worksheet, on accuracy and precision errors, reference densities for known substances Analysis of table for data collection written collectively in the whiteboard	Observation of demonstration by teacher for the large group of some of the procedures (e.g., filling in the pycnometer) Individual students, requested by the teacher, manipulate some material and equipment in front of the large group with the teacher verbalising and scaffolding students' demonstrations Student verbalisation of name of material and equipment available in trays and side benches led by teacher questioning Student verbalisation of the goal of the activity, the reasons for some of the steps of the procedure and some necessary calculations Reading of the textbook illustration with visual elements of the procedure (measuring the mass of the pycnometer and the piece of metal)
Task B – Practical work	Manipulation of materials and equipment following a procedure	Explicit association of meta-concepts such as uncertainty and specific readings of measuring instruments (thermometer) Recording on a structured table of the observed data obtained during the practical Repetition of measurements and explicit association to determination of precision of measurement
Task C – Data analysis	Calculations of density, specific gravity, errors	Use of experimental data obtained by students in the recently performed practical work for the calculations

Task	Non-iterative programme	Iterative programme
Task D - Discussion	Comparison of the obtained value for specific gravity to a *true* reference value	Verbalisation on the accuracy of measurement and possible experimental errors

6.3 Case study 3 – Elements of the SLS in activity

Case study 3 took place in a school in the Oporto Region, with a teacher that participated in most of the discussions and teacher training initiatives organised by Parque Escolar on the new school Science laboratories. Me and prof. Vitor Teodoro had been in the school for several times, before and after Parque Escolar's intervention. This case study took place in June 2014.

6.3.1 Walkthrough interviews

A walkthrough interview is a method not commonly used in Science Education but usual in post-occupancy evaluation and architectural programming. It allows the researcher to quickly understand how space works via a running commentary from users, and informal observations and photos (Gifford, 2016, p. 255) to:

1. Demonstrate how buildings support and frustrate people;
2. Illustrate diverse design requirements;
3. Document relevant recommendations;
4. Stimulate action for fine-tuning;
5. Transparently communicate design requirements.

To support this process, a walkthrough interview schedule provided a spatial agenda for participants to respond to, with the actual elements of the design acting as prompts. The goal of this interview was to elicit the teacher's attitudes, expectations and practices related to the key design elements of the Science Learning Studio. This meant that the interviews took place in the actual Studios, where the interviewer and interviewee could directly interact with space and design elements. The interviewer used a visual checklist that defined a route through the Studios, with some key stops where questions would be made.

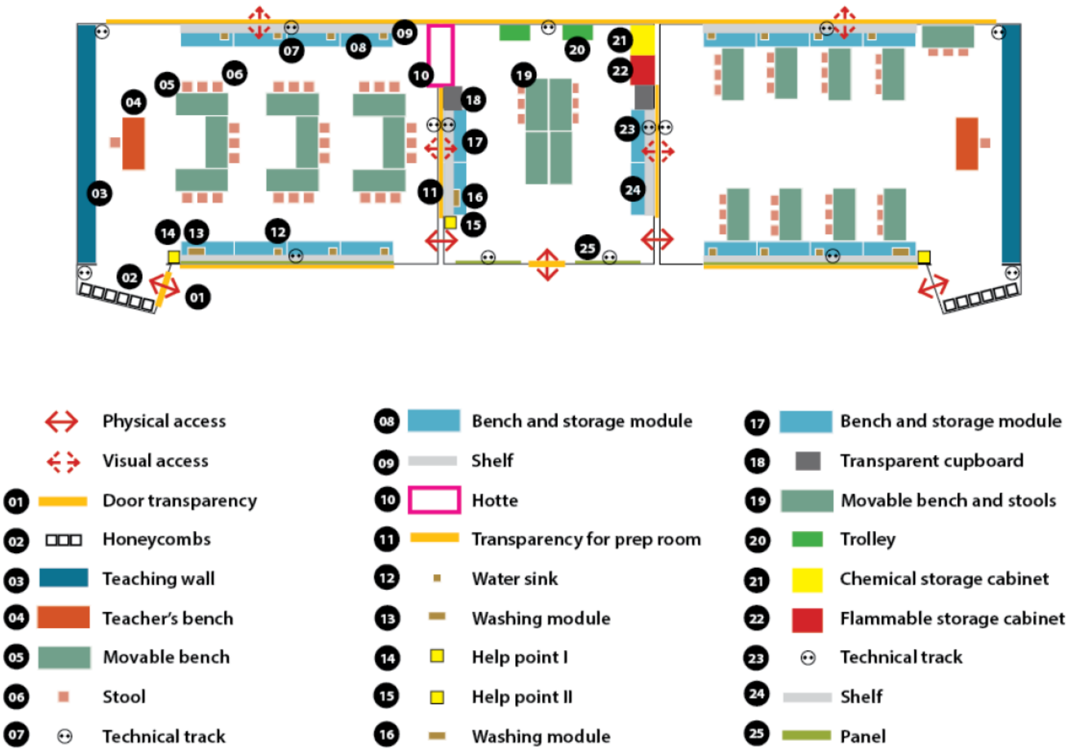


Figure 6.9 - Key elements of the SLS driving the interview route.

The key elements were identified from the model's design elements and are signalled in Figure 6.9. These options had an underlying practical and/or pedagogical rationale (Fernandes et al., 2008) that would be elicited during the interview to understand the meanings attributed by the teacher.

The above plan was adapted from a checklist made for architects, engineers and technical teams involved in the actual construction and equipment of the spaces. In the original form, it was not very useful during the actual interview because it had many repeating elements and didn't provide a pathway across space that should be easy to follow by the researcher during fieldwork. In this sense, I simplified and adapted it to the new goal.

The interview schedule had as main goals:

1. To understand how the SLS are viewed by teachers from a pedagogical standpoint;
2. To understand how the elements of the model are perceived and used in practice by teachers;
3. To understand the needs of teachers regarding the organisation, management and use of the SLS;
4. To inform the survey design.

6.3.2 School and teacher

The choice of interviewee was based on its expected understanding of the underlying concept so that she could provide better insights on the implementation of the model and maximise learning from the case.

One teacher was recruited due to her involvement in a set of events related to the implementation of the new model of schools' Science spaces by Parque Escolar (a public event in one of the pilot schools in Lisbon in 2009 presenting the new model and a 25 hours' teacher training programme on Using the new laboratories, in 2010) and a visit to the school prior to the intervention.

Cristina has been a Physics and Chemistry teacher teaching in this school for 17 years. She participated in a seminar in September 2009 presenting the first iteration of the SLS model to the wider community, in one of the pilot schools, Secondary School D. Dinis, in Lisbon. She was also a trainee in the teacher training course in 2010 Using the new laboratories, together with 109 teachers from across the country teaching in the new schools. This course had as the main goal to communicate the rationale of the model and provide guidance to:

1. Analyse and debate strengths and weaknesses of diverse models of organising schools' Science laboratories, both nationally and internationally;
2. Prepare practical activities for small groups, simulating the typical conditions of laboratory lessons for half-class;
3. Prepare practical activities for large groups, simulating the typical conditions of laboratory lessons for the whole class;
4. Analyse and debate strengths and weaknesses of diverse models of practical activities;
5. Analyse and debate several models for organising equipment and chemicals;
6. Gather information on providers, equipment and materials for schools' Science laboratories.

The design elements of the SLS mentioned in section 2.5.7 acted as prompts during the walkthrough interview, organised into a path that guided the interview in the actual laboratory and prep room.

Oporto school

1. Typology: MOP | JCETS – Industrial and Commercial School;
2. Inauguration: 1964;
3. Capacity: 60 classes;

4. Location: Oporto region;

5. Phase 1 | 2007-2008.

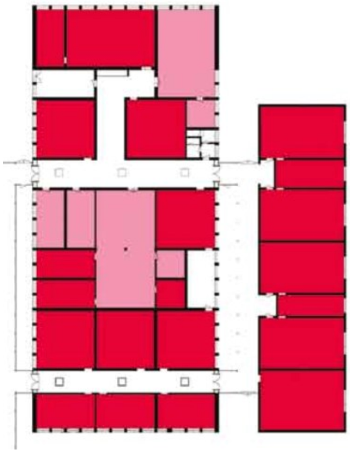


Figure 6.10 – Plan of Secondary School in case study 3, with the Science labs located on the right side, after the corridor (Parque Escolar, 2009, scale not visible in the source)

6.3.3 Data and analysis

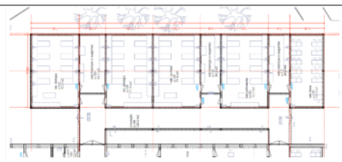
In the following table, the several elements of the SLS are analysed per the teacher's replies to the walkthrough interview. Whenever possible, the elements are illustrated with photos.

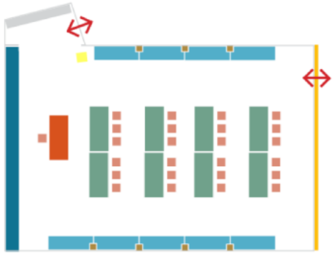
Table 6.5 – Analysis of the elements of the SLS, with photos and observations

Element	Checklist	Figures	Observations
01 Door transparency	Not present		A possible alternative to the transparency by keeping the door open during the lessons was discussed with the teacher and was not considered practical as other classes made too much noise

Element	Checklist	Figures	Observations
02 Honeycombs	Present, not used for students' bags and coats		There was the need for more storage space, so the honeycombs were used in the prep room and lab for storing material and equipment, books or even for exhibiting students' work. Side benches were used to keep students bags and coats
03 Teaching wall	Present		Behind the sliding doors, it would be useful to have horizontal space for large items such as tracks (Physics)
04 Teacher's bench	Present		-
05 Movable bench	Present		The benches were considered somewhat heavy, limiting the flexibility of arrangements. However, change in the arrangement was said to be common by this teacher. Other teachers do not change bench arrangement according to her
06 Stool	Present, without back support	Check 05	Uncomfortable, noisy, no back support, feet support quickly detached and damaged
07 Technical track	Present, with protection		Protection in electrical plugs (not mentioned in the proposed model) do not make sense for the secondary level of education
08 Bench and storage module	Present	Check 07	No master key demanding 24 keys per laboratory. No

Element	Checklist	Figures	Observations
			drawers' module, regular or large (for burettes for example)
09 Shelf	Present	Check 07	Used for exhibiting students work
10 Hotte	Present, in lab	Check 04	More useful in the lab instead of the prep room, for use with the students
11 Transparency for prep room	Not present	-	-
12 Water sink	Present	Check 07	-
13 Washing module	Present		Useful in the lab for students to help in washing material. No connection to the main hot water circuit makes washing difficult
14 Help point I	Present, dispersed		Eye washer/shower in washing module in one of the corners of the lab, and fire blanket and fire extinguisher in opposite corner
15 Help point II	Present, incomplete and dispersed		First aid kit not close to eye washer/shower. No fire blanket or extinguisher
16 Washing module	Present, no hot water		No hot water and no shelf to support washing and drying
17 Bench and storage module	Present		

Element	Checklist	Figures	Observations
18 Transparent cupboard	Not present	-	-
19 Movable bench and stools	Not present	-	-
20 Trolley	Not present	-	-
21 Chemical storage cabinet	Present	Check 17	Ventilation of the storage cabinets was considered very important
22 Flammable storage cabinet	Present	Check 17	-
23 Technical track	Present	Check 17	-
24 Shelf	Not present	.	-
25 Panel	Present (later added)	Check 17	The panel/cork board later added did not have any relevant information
Areas	Very small prep room	Check 17	A large prep room could be also used for practical activities or interactive demonstrations
Ventilation, thermal comfort and indoor air quality	Week natural ventilation		The window opening mechanism did not allow sufficient ventilation
Lighting	No sufficient natural light	Check above	Window sizes and building orientation required all day artificial light
Acoustics	No reference	-	-
Colour scheme	Black, white, green	-	-
Waste management	Only general waste recipients	Check 13	No recyclable containers, as expected in the new model
Decoration	On top of the teaching wall and shelves		Parque Escolar does not allow to stick student's work or posters to the walls
Allocation	Only for half-class, practical. 2 labs and 1 prep room for Biology and Geology, 2 labs and 1 prep room for Physics and		Number of labs higher than before the intervention

Element	Checklist	Figures	Observations
	Chemistry and 1 lab polyvalent		
Main configuration	"Regular classroom". This specific teacher changes the configuration in practical lessons		Before the intervention, the Physics and Chemistry lab had fixed central benches
Transition			Expectations not well managed as the idealised model is different in implementation

6.4 Case studies 4 and 5 – Organisation and management of the SLS

Contextual task analysis is a common method for developing user interfaces. It focuses mainly on the behavioural aspects of a task, with the goal of understanding the general structure and flow of tasks. Besides this understanding, it also identifies the main artefacts that support the task, information needs, exceptions and workarounds to normal work activities. The outcome of this method is a flowchart with a supporting narrative focused on users' tasks and goals, information required to achieve these goals, information generated from achieving these goals and task structure, with subtasks and interdependencies (Salvendy, 2001):

> Task analysis thus aims to structure the flow of task activities into a sequential list of functional elements, conditions of transition from one element to the next, required supporting tools and artifacts, and resulting products (Sheridan 1997a). Such an analysis can be driven by formal models such as TAKD (task analysis for knowledge description; see Diaper 1989) or GOMS (goals, operators, methods, and selection rules; see Card et al. 1983) or through informal techniques such as interviews, observation and shadowing, surveys, and retrospectives and diaries (Jeffries 1997). Interviews are the most common informal technique to gather task information (Jeffries 1997; Kirwan and Ainsworth 1992; Meister 1985). In this technique, informants are asked to verbalize their strategies, rationale, and knowledge used to accomplish task goals and subgoals (Ericsson and Simon 1980). As each informant's mental model of the tasks they verbalize is likely to differ, it is advantageous to interview at least two to three informants to identify the common flow of task activities. Placing the informant in the context of the task domain and having him or her verbalize while conducting tasks affords more complete task descriptions while providing insights on the environment. Whether formal or informal techniques are used, the objective of the task analysis is to identify the goals of users and determine the techniques they use to accomplish these goals. Norman (1988) provides a general model of the stages users go through when accomplishing goals. (p. 1208)

To perform the contextual task analysis, data was collected in the first school (case study 4) during 3 visits across 2 years, the first in June 2014, the second in July 2014 and the third in April 2015. In the first visit, an unstructured interview with the operational assistant aimed to understand her background, space and information organisation, and some of the resources used to support the organisation and management of the laboratories. Photos were taken during the interview together with notes and audio in the DRN.

The second visit, following a timeline since the beginning of the school year, aimed to prepare a storyboard identifying the main tasks and subtasks with the necessary resources and document templates in the organisation and management of activities in the SLS. Documents were collected and scanned, and photos were taken, associated to notes in the digital research notebook.

In the third visit, tasks in real time were observed and the result of the task analysis in a storyboard was reviewed with the assistant.

In the Setubal school, a 2-hour visit took place in April 2016. An unstructured interview was made following the two teachers during the visit to the several laboratories and prep rooms, using the tasks identified in the Algarve school to support questioning associated to what was observed in the spaces. Photos were taken, and the interview was transcribed, associated with photos and corresponding tasks.

6.4.1 Schools, operational assistant and teachers

Marilia, one operational assistant acting as laboratory technician was recruited in a serendipitous visit to a secondary school in the Algarve region, during a seminar about the national exams in July 2014.

Teresa and Maria, two Physics and Chemistry teachers, one of them the head of facilities, were recruited through the Teacher Training Center "Ordem de Santiago" in Setúbal, from a new secondary school delivered by Parque Escolar in the beginning of the school year 2015/2016, in the Setubal district.

Table 6.6 – Summary of people, roles and schools recruited for performing a contextual task analysis about the organisation and management of SLS

Teacher/Assistant	School	Role	Gender
Marilia	Algarve (A)	Operational assistant acting as laboratory technician	Female
Teresa	Setubal (B)	Physics and Chemistry Teacher	Female

Teacher/Assistant	School	Role	Gender
Maria	Setubal (B)	Physics and Chemistry Teacher, Head of facilities	Female

Algarve school

1. Typology: MOP | JCETS – Industrial and Commercial School;
2. Inauguration: 1964;
3. Capacity; 36 classes;
4. Location: Algarve region;
5. Phase 3 | 2009-2011 (incomplete during case study in 2014 and 2015).

Figure 6.11 – Floor 1 plan for school A. The Physics and Chemistry laboratories, prep rooms and remaining spaces, are signalled with a dashed box (scale not visible in the source)

Marilia has been an operational assistant for 22 years. She concluded 12 years of education in a public school. She always had a strong interest in laboratories management and usually acted in a *de facto* role of laboratory technician, participating in training and continuously developing documents, templates and workflows, organising space and equipment, assisting teachers in preparing and delivering practical activities and managing the Physics and Chemistry laboratories for the entire school year. During a conversation between myself and one of the teachers in this school, she mentioned that she was very satisfied with this type of support, something she did not see in other schools. Usually, she only needed to inform Marilia of small changes she decided to do in a certain practical activity. For the remaining time, Marilia always knew which practical activity was coming next. She was now not fully dedicated to the laboratories, due to recent limitations in assistant personnel in school.

Marilia used on of the prep rooms has a general headquarters for managing the set of 6 laboratories. On the north side of the corridor were the Chemistry laboratories, and on the south side mostly the Physics laboratories and a Polyvalent laboratory for years 7 to 9.

Setubal school

1. Typology: Pavilion | 3×3 blocks;
2. Inauguration: 1987;
3. Capacity: 66 classes;
4. Location: Setubal region;
5. Phase 3 | 2009-2010.

Figure 6.12 – Ground floor and floor 1, with the Science area signalled with a dashed box (scale not visible in the source)

Even though this second school (case study 5) was projected in 2009-2010, due to financial limitations by Parque Escolar after 2010, the intervened school was only delivered in August 2015. The Science teachers only had the first weeks of September to organise the equipment and materials and prepare the new school year starting in mid-September. With the new laboratories, there was more than enough storage room for the limited quantity of materials and equipment available, with many storage modules still empty. There were no recent participations in school projects in the group, despite a team of 12 teachers. Four laboratories, with 2 prep rooms and chambers were allocated to the Physics and Chemistry subjects, with those on the 1st floor attributed mostly to years 7 to 9 and those on the ground floor to the secondary level. Opposite the corridor, the same distribution was given to Biology and Geology. No theory lessons were allocated to the laboratories.

Teresa has been a Physics and Chemistry teacher, and for several times the head of facilities for the Physics and Chemistry group. She was a teacher for 22 years in school B. Maria has been also a Physics and Chemistry teacher for 19 years in this large school, and the acting head of facilities for her group.

6.4.2 Data and analysis

In the following section, the tasks and workflow will be presented, categorised by the main role using the SLS: teachers and/or lab technicians and heads of facilities. For each task, there will be goals and subtasks, information and resources required for goal accomplishment, justified by evidence gathered in both schools, illustrated with photos.

Tasks, subtasks and programme by role

In the following section, the multiple tasks, subtasks and programme are synthesised by role (teachers/lab technicians and heads of facilities), from the unstructured interview and the observations made in the visits to the two schools.

Roles: Teachers and/or laboratory technicians

Teachers and/or operational assistants acting as laboratory technicians have a programme of tasks prior to the activity, during the activity, after the activity and in case of emergency, resumed in the following list.

Pre-activity

1. Coordinate the activities timetable between the team;
2. Consult textbook and/or selected activity protocol(s);
    a. Check if in use by another teacher;
3. Locate materials, equipment and chemicals:
    a. Check inventory and location;
    b. Move to preparation area;
    c. Consult material safety data sheet(s) if required;
    d. Consult equipment manual(s) if required;
4. Prepare trays;

5. Identify trays;
6. Reserve trays for class.

During activity

1. Move trays between prep room and laboratory;
2. Provide daily use materials to students (distilled water, active safety equipment, etc.).

Post-activity

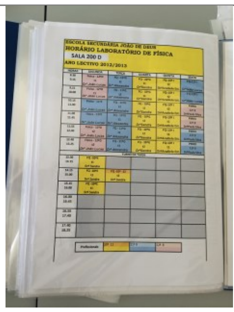
1. Wash and dry materials;
2. Store equipment, materials and/or chemicals OR transfer to another teacher/class;
3. Reserve (only for activities on hold);
4. Update stocks and inventory if necessary, prepare acquisitions;
5. Manage waste.

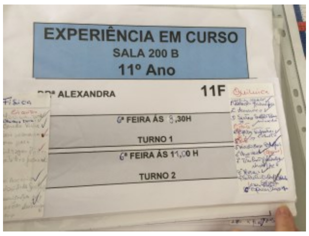
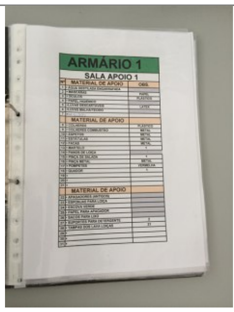
In case of emergency

1. Access active safety equipment;
2. Use standard protocols to minimise damage and/or apply emergency plan;
3. Register occurrence.

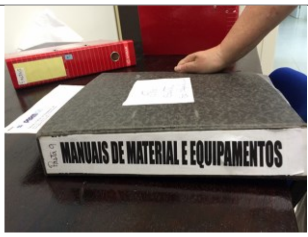
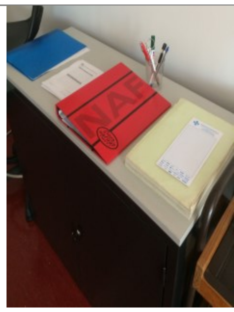
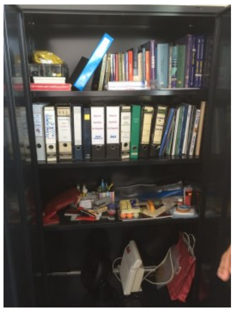
In the following table, the structure of these activities will be associated with the information needs and resources required by teachers and lab technicians, based on observations in both schools.

Table 6.7 – Contextual task analysis in schools A and B for the roles “teacher and lab technician

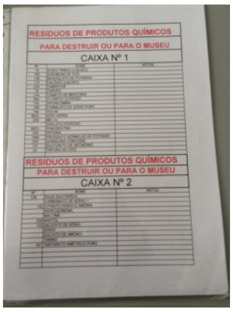
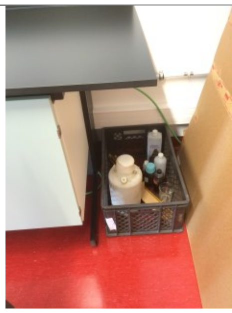
Task and goal	**Information needs and resources**	**Observations in School A**	**Observations in School B**
Define activities timetable **Goal:** To plan preparation of activities ahead	What practical activities are planned by teachers in every grade across the term/year? When are these activities expected to take place? **Resources:** Request forms for preparation of activity Activity timetable/calendar School year calendar Teachers’ timetables	 Timetables are defined by the assistant in the beginning of the school year, with one for each laboratory with a colour code	The activities timetable is coordinated between teachers in group meetings and the group tries to be synced in practical activities (in the maximum 2 weeks to have all the same practical activity concluded in all classes of the same year)

Task and goal	Information needs and resources	Observations in School A	Observations in School B
			
Consult textbook and/or selected activity protocol(s) Check if in use by another teacher **Goal:** To understand the materials and protocol required for the planned activity	Where are the textbooks and/or selected activity protocol(s)? **Resources:** Textbooks/protocols used in all grades Activity timetable/calendar Teachers timetable	 In a document tray, with one separator for each secondary year, there are textbooks and a control document "Ongoing activities" for each class, where the assistant signals the activities already concluded and can easily plan her work between classes 	Teachers usually carry textbooks in their bags and use them when preparing activities. They talk to colleagues or check the trays in the prep room to see if the required resources are in use
Locate materials, equipment and chemicals **Goal:** To begin preparation of the planned activity	Where is the inventory and chemical stocks for search and retrieval? How do I search and retrieve the location code and associate it to the actual location? Are the locations accessible or is permission or keys required to access them? Where are the keys? **Resources:** Inventory and chemical stocks with location codes associated with each entry Plan associating location codes to actual storage modules Keys	 In a folder dedicated to the inventory, besides the general inventory made in word and printed, there is also an inventory by storage module. Every laboratory has a colour code to facilitate the finding of keys, timetables, ongoing activities and inventories.	 All storage modules have the same organisation across laboratories. Those on the right of the teaching wall have materials and equipment for Chemistry and on the left, for Physics. Chemicals are stored in the flammable storage cabinet or the acids and bases cabinets, in alphabetical order.

Task and goal	Information needs and resources	Observations in School A	Observations in School B
	Signage in storage modules with location codes	 The numbering of storage modules is consistent across labs and these have labels close to the locker, so the assistant identifies the storage module and gets the required key to open it, in a keyring with the colour attributed to the laboratory.  Some material is stored in transparent boxes inside storage modules as activity kits (e.g., distillation)	  In the teaching wall, there is also stored glassware Keys are kept in a drawer, in a key ring per laboratory, but most of the storage modules, including chemicals, are open
Gather all required resources for the activity and move to preparation area **Goal:** To facilitate preparation of trays and experimental apparatus	Where is the preparation area? Where are the materials and equipment to support preparation? **Resources**: Space for preparation General materials and equipment to support preparation	 There is a preparation bench, usually uncluttered, located in the prep room, close to the storage of most of the glass material and with trays easily accessible  There are general materials useful for preparing the trays nearby, that are also commonly used during lessons (distilled water, gloves, protective	There is a set of benches in the prep room to support the preparation of practical activities

Task and goal	Information needs and resources	Observations in School A	Observations in School B
		goggles, absorbent paper, pipettes)	
Prepare trays and/or experimental apparatus Consult material safety data sheet(s) if required Consult equipment manual(s) if required Consult instructions for preparing solutions or apparatus **Goal:** To have resources ready ahead of lessons Assess risks	Where are the material safety data sheets? Where are the equipment manuals? Where are the instructions to support preparation? **Resources:** Trays Folders with MSDS, Equipment manuals, instructions for preparing solutions or apparatus	 During the preparation, different information is required, organised in folders or in notebooks in the office room 	 In the prep room there is a bench with a folder containing activity forms  In the group's room there is also a cabinet with folders and textbooks with relevant information
Identify trays and reserve for class **Goal:** To know which class the trays are for and avoid use by other teachers	What labelling is available and how is it used? Where should the trays be kept before the lesson? **Resources:** Labels and pen Space for placing trays waiting for the activity to take place	 After the preparation stage, trays are placed in nearby trolleys, with an activity information sheet identifying the activity. This information sheet has the required material, quantities, chemicals, concentration, formula and type of container, information on elimination, risks, notes and some photos	 Trays are placed on a side bench, with a form identifying the activity for each set of trays 

Task and goal	Information needs and resources	Observations in School A	Observations in School B
			
Move trays between prep room and laboratory **Goal:** For delivery of trays and apparatus to teacher and students during the lesson	Where is the trolley parking area? **Resources:** Trolleys Space for parking trolleys	The trolleys are parked in an easily accessible place between laboratories. The assistant, through the transparency to the adjacent laboratories or the corridor, can provide support to teachers when required. The transparency between laboratories and prep room is partially covered with paper, justified by the risk of students of different classes being distracted with one another 	 Trolleys are parked in the prep room near the entrances to both adjacent laboratories
Wash and dry materials Store equipment, materials and/or chemicals OR transfer to other teacher/class Reserve trays for activities on hold **Goals:** For future retrieval and use of resources	Where are the washing support equipment located? Where are the drying equipment and what the protocols to use them? Where should the resources for transfer to other teachers be kept and signalled? Where should activities on hold be stored? **Resources:** Washing module Washing equipment Instructions for cleaning special equipment or materials Labels Space for activities on hold	 The washing module has all the required equipment nearby (cleaning products, drainers, pipe cleaners, cloths, bins). A stove is next to this are to support drying	 The washing module does not have supporting material and equipment for washing. In the washing module in the laboratory, there is a drainer for glassware
Update stocks and inventory if necessary, prepare acquisitions **Goal:** Maintain stocks for future activities	How should the stocks and inventory be updated? What is the process and time of acquisitions? What providers are adequate? **Resources:** Broken material, needs or equipment failure forms	 	The inventory and acquisitions are done by the head of facilities, using digital files and school forms

Task and goal	Information needs and resources	Observations in School A	Observations in School B
	Catalogues Providers and contacts Acquisition form Folder for registration of process of acquisition and losses	In a panel in the prep room, there are several forms to annotate broken material, equipment failure and needs These are helpful to update the stocks, inventory and prepare acquisitions. Besides that, folders with acquisition forms, previous acquisitions, catalogues and providers contacts support this process	
Manage waste **Goal:** Avoid safety risks, environmental hazards or accumulation of waste	What are the waste management protocols of the activity? Do they need to be labelled and kept for future elimination? What companies provide waste management services? **Resources:** Folder with waste management information Waste management company contact Waste containers Spill kit Waste labels Waste stock Folder for registration of waste management services and contacts	 Next to the washing module, there are several containers to store waste. In the activity sheets, there is some information for waste elimination and also on the MSDS. There are also labels in each container and an inventory of waste. When needed, a waste management company is contacted to remove certain types of waste 	 Waste is stored in a box in the prep room
Access active safety equipment Use standard protocols to minimise damage and/or apply emergency plan Register occurrence **Goal:** Insure safety of students and staff in case of emergency		Some of the safety equipment in concentrated in an area with easy access, from both the laboratories and the prep room to serve both A copy of a first aid manual is available for consultation in an accessible area A spill kit is located next to the washing module (recipients with sand and sawdust)	 There is a spill kit available, next to the first aid kit and the waste box

Role: Head of facilities

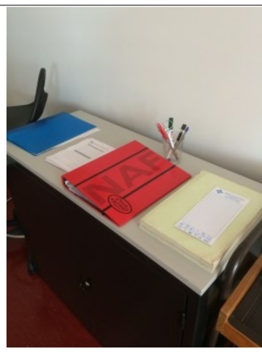
The head of facilities has a set of tasks beyond those of teachers and operational assistants. In school B, these tasks were more easily elicited as the group recently moved to new facilities and many of these tasks had to be performed:

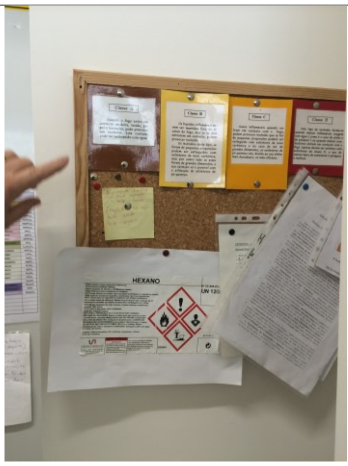
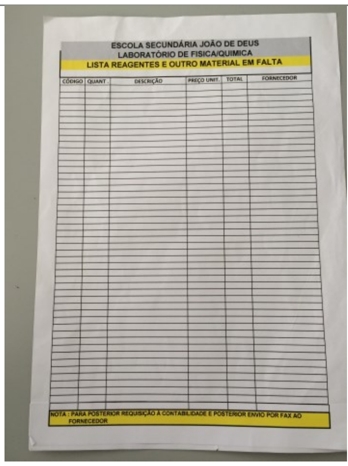
1. Define functional areas;
2. Define regulations and protocols;
3. Define storage logics (materials, equipment and chemicals);
4. Apply and maintain relevant signage and communication;
5. Maintain inventory and stocks;
6. Manage acquisitions and elimination of waste;
7. Control the review of safety equipment and conditions;
8. Manage information (folders, notebooks, agenda, timetables, digital documents and templates).

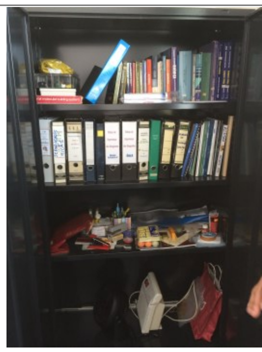
In the following table, the structure of these tasks will be associated with the information needs and resources required by heads of facilities, based on observations in both schools.

Table 6.8 - Contextual task analysis in schools A and B for the role of head of facilities

Task and goal	Information needs and resources	Observations in School A	Observations in School B
Define functional areas **Goal:** Optimise space organisation for activity preparation and follow-up	What are the required functional areas? Where should these areas be located? **Resources:** Furniture, equipment and materials	Some of the safety equipment in concentrated in an area with easy access, from both the laboratories and the prep room to serve both A spill kit is located next to the washing module (recipients with sand and sawdust)  There is a bench dedicated to preparing trays and another to activities waiting for follow-up A corkboard is located next to the prep room entrance with the timetables of the laboratories and other useful information	A spill kit is located next to the waste containers  A bench is reserved for storing prepared trays for activities

Task and goal	**Information needs and resources**	**Observations in School A**	**Observations in School B**
		A corkboard is located in the prep room with table to register broken material and acquisition needs A waste area concentrates the recipients for several types of waste A bench area has all the required materials for daily use during activities 	 A bench has several resources for daily use of staff
Define regulations and protocols **Goal:** Optimise management and maintain safety	What regulations and protocols are required to optimise management and maintain safety? **Resources:** Document with regulations and protocols accessible to staff	-	The regulations for the Physics and Chemistry laboratories are available to the group in the prep room
Define storage logics **Goal:** Optimise organisation of materials and equipment to facilitate management and access	How should storage modules in labs and prep rooms be organised? How are chemicals stored? How do the inventory and stocks integrate location information? **Resources:** Plan of the storage modules Plan of chemicals storage Template for inventory and stocks	Each lab and prep room is color coded, with labels in storage modules associated with the inventory Chemical storage is organised by categories of chemicals Storage modules close to the teacher have activities kits in transparent boxes In the physics storage room, equipment and material is organised by theme (Optics, etc.) Glassware is concentrated in the Chemistry prep room	The chemical storage is organised by categories of chemicals

Task and goal	Information needs and resources	Observations in School A	Observations in School B
Apply and maintain relevant signage and communication **Goal:** Facilitate communication among staff Facilitate retrieval of information, material and equipment	What is the relevant signage and information to be easily available to the space users? Where should it be placed? **Resources:** Posters Templates for labels Printable documents	 Information about types of fire and fire extinguishing procedures is placed near the chemical storage Lab rules posters are placed in every lab Signage for some prohibitions is placed in the door to the prep room Labels in storage modules have the colour code of the lab and the identification of each one, and in some cases its content listed Useful contacts are placed on the wall close to the telephone	
Maintain inventory and stocks **Goals:** Supply for the needs of staff in activities Control budget	How are gains and losses registered? What fields should the inventory and stocks have? **Resources:** Digital and/or paper inventory and stocks Forms for registering losses	The broken material form in the prep room facilitates inventory updates, in digital format (Word document)	-
Manage acquisitions and elimination of waste **Goals**: Supply for the needs of staff in activities Control budget Maintain environmental and safety conditions	What companies provide waste management services? **Resources:** Folder with waste management services contacts Labels for waste categories containers and specific waste Inventory of waste	 ESCOLA SECUNDÁRIA JOÃO DE DEUS LABORATÓRIO DE FISICA/QUIMICA LISTA REAGENTES E OUTRO MATERIAL EM FALTA CÓDIGO | QUANT | DESCRIÇÃO | PREÇO UNIT. | TOTAL | FORNECEDOR NOTA: PARA POSTERIOR REQUISIÇÃO À CONTABILIDADE E POSTERIOR ENVIO POR FAX AO FORNECEDOR	-

Task and goal	**Information needs and resources**	**Observations in School A**	**Observations in School B**
		A form for placing acquisition needs is placed in a corkboard	
Control the review of safety equipment and conditions **Goal:** Maintain standard of safety conditions	What are the main conditions requiring review for safety purposes? When should they be done? **Resources:** Checklists for review	A safety checklist for a yearly review of safety conditions is available	-
Manage information and information access **Goal:** Facilitate information search and retrieval	What information is required in the use of labs and prep room? How can it be searched and retrieved? What is the archiving policy? **Resources:** Folders and digital folders and corresponding inventory Access policy Archiving policy	Folders are organised and labelled, containing information related to several aspects of laboratory activity, placed in a daily use area or in the archive Digital templates and documents are stored in a non-shared disk	 Folders are stored in the Physics and Chemistry teachers' office

6.5 Coda

In this chapter, 5 quite different case studies were presented: the first, attempted to characterise some of the activities taking place in an open inquiry Science subject (AP); the second applying the SLS Activity Analysis Methodology to a Pedagogical Graphic novel of a year 10 practical Science lesson; the third, tried to understand how the elements of the Science Learning Studio were viewed by a science teacher in an intervened school; and finally, the fourth and fifth case studies, trying to understand the organisation and management aspects of the Science Learning Studio.

These quite different case studies informed the quantitative study and had the goal to develop everyday useful solutions for teachers and students, in particular a model of organisation and management of the SLS.

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7. Attitudes, expectations, and practices in the Portuguese secondary schools' Science Learning Studios – A survey

This chapter reports on attitudes, expectations and practices in the SLS gathered from Science teachers teaching in the schools intervened by PE since the school year 2008/2009. Data was collected in July 2015 from 24 respondents from 18 identified schools, using an online questionnaire disseminated through an email campaign to a total of 118 teachers (20 % response rate) in 62 schools (29 % response rate).

The qualitative stance taken in the empirical part of this research project provided important contributions to the design of the survey, both technically, conceptually and in the development of questions. For example:

1. The selection and illustration of teaching and learning activities in theoretical, practical, open enquiry and project lessons used in the survey was made from data collected in the ethnographic case studies;
2. The concept of storyboard, later replaced by Pedagogical Graphic Novel, was used to illustrate the use of the elements of the model of the SLS, based on a 3D model of the SLS and a workflow to digitally represent activities in the SLS.

Informed on the review of the literature on questionnaire design, internet-based surveys (Cohen et al., 2007) and online surveys' web applications, the aim was to design a survey that:

- Looked easy, attractive and interesting and was enjoyable to read and answer. The typography, colours, illustrations and the survey theme were carefully selected to achieve this end;
- Was informational on the concept of the SLS. This was achieved through the illustrations provided on the elements of the model in use, that reflected the view of the design team;
- Provided concrete situations in the SLS for teachers to reflect upon, with visual information supporting meaning making across questions, particularly those related to

use of certain elements of the SLS and teaching and learning activities. The illustrations from data collected in the ethnographic case studies supported these concrete situations, that had also an abstracted description to facilitate teachers' transfer to their own practice;

- Made clear the goals of the questions, sharing with the respondents the meaning that could be obtained from its answers. The email sent in the campaign, the initial introduction to the questionnaire and the introductions to sections of the questionnaire were designed in this sense;
- Made responses available to the respondents. When the respondents completed the questionnaire, they had the option of receiving their responses by email and viewing a preliminary data analysis of the responses given at the time;
- Made data available to the larger Science Education community, through a digital repository and the website of the SLS, http://laboratoriosescolares.net.

The 73 questions were organised into 5 groups/pages:

1. Basic information about the respondents;
2. Use of the new Science laboratories;
3. Teaching and learning activities in the new Science laboratories:
4. PE intervention;
5. Detailed information about the respondents.

In the following sections, the questionnaire development will be summarised, followed by an explanation of the sampling method, the validation and pilots made before release, the email campaign, the presentation of the data and its analysis, followed by a reflection on the contributions of this method to answering the research questions and its possible implications.

7.1 Development

The initial idea to design a web-based survey was to easily and cheaply reach a sample spread across the country. The literature provided guidance in the design of the web survey, on aspects such as:

- Ethics (anonymity guaranteed by the web application, informed consent);
- Technical (responsive behaviour across browsers, easy download even with low-speed internet connections, down sampling images to reduce file size);

- Respondents (providing clear instructions, close to the actual questions whenever necessary, limiting responses per user with unique links generated by the software);
- Layout and presentation (creating multiple sections and headings, avoiding grids and matrices, requesting basic information on respondents at the beginning as a warm-up) (Cohen et al., 2007).

This survey intended to gather data at a particular point in time with the intention of describing the nature of existing conditions or identifying standards against which existing conditions can be compared (Cohen et al, 2007, p. 205), providing factual information, data on attitudes, behaviour and experiences for a broad-brush on how the model of SLS was received and used in the schools intervened by PE.

Departing from the research questions, an identification and itemising of subsidiary topics took place, related to the use of the SLS focused on its design elements, the activities that it was designed to support, organisation and management aspects that could be related to the implementation of the model, and so on.

To obtain a snapshot on the use of the design elements, it was necessary to obtain information on when was the school intervened, for how long were teachers in the school before and after the intervention, what kind of involvement did they have in the intervention, which design elements were actually implemented in the schools, how do teachers used them compared to the envisioned use and what reasons they put forth to justify their practices, what aspects of activities do they most value, and so on. Question types were selected to obtain the intended information, from closed (dichotomous, multiple choice, rating scales) to open. Several answer options were selected based on the experience of previous contacts with hundreds of teachers and visits to many schools across the country from 2008-2015, related to the research project or with the lead consultant for PE, Prof. Vitor Teodoro.

One issue that was difficult and time-consuming to solve was how could the use of the design elements of the SLS be presented to the respondents in a way that would facilitate situatedness, as in the case of the walkthrough interviews?

7.1.1 Providing concrete situations for teachers to respond to

The storyboard concept, previously acquainted in the case studies in this study, was thought of as a clearer way for teachers to identify the practices afforded by the new design elements, providing concrete examples to which participants could respond to.

Several experiments with a 3D model of the SLS in Google Sketchup produced by an architect participating in the project (André Pereira) were made to recreate simulated or recalled activities. Manipulating the model towards the intended views, and later illustrating situations, as already explained in section 5.1, was useful in designing these concrete examples.

Figure 7.1 – Example of illustration of an element of the SLS in use (Teaching wall)

7.1.2 The choice of an online survey web app

The choice of an online survey web application began with testing the Limesurvey open source software, installed and configured in a web server and with preliminary questions later added. The application remained unsatisfactory due to its limited features on managing email campaigns, providing the response set to each respondent, facilitating the choice of themes and typography, providing question types and generating preliminary data analysis. Through web searches, three applications were identified that could fulfil these limitations: Survey monkey, Fluidsurveys and Surveygizmo. The company philosophy, price structure and software features contributed to the choice of Surveygizmo as the questionnaire web application.

7.2 Sample

The sample is not representative of the total population of the intervened schools at the time of the questionnaire (115 schools according to Hélder Cotrim, an architect in Parque Escolar, personal communication, May 2015), with a non-random selection method chosen for convenience. The initial target of the email campaign were 118 Science teachers from 62 schools that participated, as previously mentioned, in a teacher training course entitled Using the new Science laboratories, led by Prof. Vitor Duarte Teodoro. I was part of the training team. The participants in this course were selected internally by the intervened schools, from both scientific subject groups, and it was suggested by the course organisers that they should be heads of facilities. The course had the support of PE, DGIDC and FCT-UNL and took place during 2010 in 5 locations across the country, with 6 classes participating in 2 sessions taking place in each.

7.3 Validation

The validation process took place with the support of 6 female teachers from both intervened (4, in schools from phases 0, 2A and 3) and not intervened schools (2), my previous acquaintances from both visits to schools and projects. All were Physics and Chemistry teachers, with roles of head of facilities in two cases. One of the teachers was co-author of the LBFQ and director of a teacher training centre and another one was a teacher trainer in the course Use of the new Science laboratories, despite being a teacher in a non-intervened school.

During the pilots, I accompanied the filling of the questionnaire by the respondents, either in person or through VoIP with screen sharing, registering every comment made on instructions, layout, clarity, wording, semantic differential options, response categories and consistency across web browsers, and later incorporating any necessary changes. Time taken to respond varied between 45 and 60 min.

The email campaign was tested with two email accounts, and all the messages sent to the respondents were trialled with these accounts (initial, reminders, final with responses attached).

7.4 Campaign

The email campaign began with a message sent to the 118 teachers from 62 intervened schools explaining the research project, the goals of the questionnaire and the participation in the previous teacher training course as a motive for contacting them. Eventual respondents were invited to reply to this first email with an OK if they agreed to participate in the study. Later, through Surveygizmo, the remaining email campaign was managed through the software. The second email was sent in this way to 31 eventual respondents that agreed to participate in the previous stage, providing instructions and a web link to access the online questionnaire. The questionnaire was kept online for 15 days, with 2 email reminders being sent by the end of the first 7 days and the second 2 days before the closing of the online survey. 27 responses were obtained, with 3 blanks being eliminated from the start, resting 24 that provided the data for analysis.

7.5 Data and analysis

A data analysis report generated by the online survey application was used for a preliminary data analysis and commented in PDF for possible approaches to data analysis (both individual responses and aggregated results).

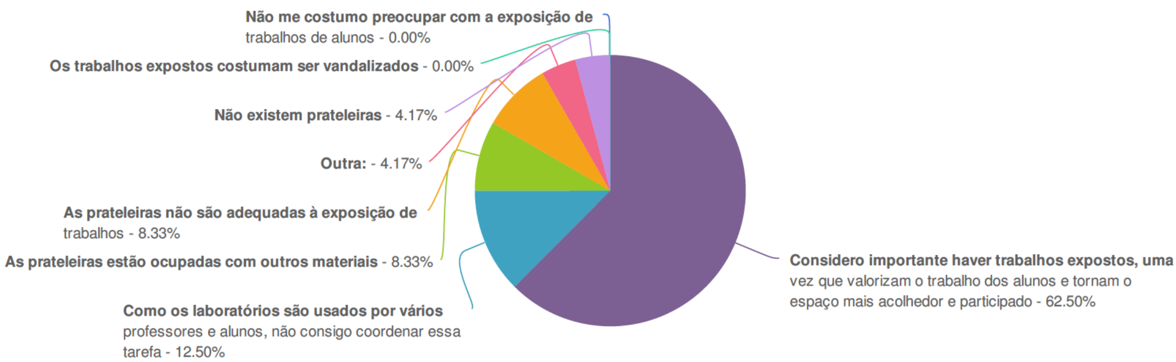


Figure 7.2 – Example of graphical display of summary report generated by the web application (question 35)

The data was exported in a CSV format and later analysed using Excel 2016 and XLStat, mostly through descriptive statistics for both qualitative and quantitative data and with pivot tables for basic cross tabs if required.

This analysis was organised in the following topics, combined with comparisons with the LBFQ when useful:

1. Schools and teachers;
2. Use of the elements of the SLS;
3. Activities taking place in the SLS;
4. Parque Escolar's intervention;
5. Organisation and management of the SLS;
6. Detailed characterisation of teachers.

Part of these topics relate directly to the research questions of this investigation and will be systematised in the Coda section in the end of this chapter.

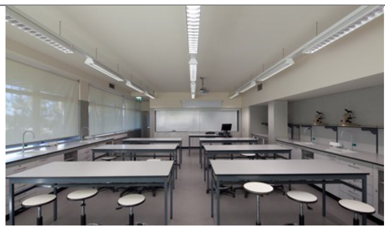
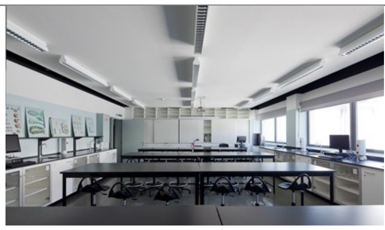
7.5.1 Schools and teachers

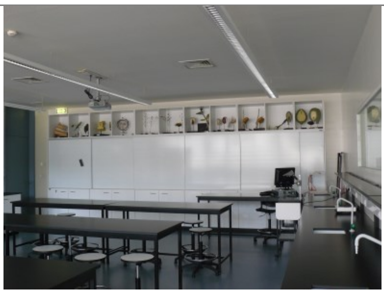
From a total of 24 responses, 18 schools were identified. There were 2 teachers from the same school in 4 situations, from distinct subject groups (Physics and Chemistry and Biology and Geology). Two respondents did not identify their school. In the following table, the schools are briefly localised and characterised, with a photo of one of the labs, the intervention phase, architecture project year and typology of intervention by Parque Escolar.

Schools

Table 7.1 – Schools from which respondents belonged to, districts, photos, intervention phase, project year and typology (figures from Parque Escolar, n.d.)

School	District	Photos	Intervention phase	Project year	Typology
Ponte de Sor	Portalegre		2A	2008/2009	Pavilion ǀ 3×3 blocks
Rocha Peixoto	Oporto	-	1	2007/2008	Industrial and Commercial
João Gonçalves Zarco	Oporto		1	2007/2008	Industrial and Commercial
Domingos Sequeira	Leiria		2A	2008/2009	Industrial and Commercial
Manuel Gomes de Almeida	Aveiro	-	1	2007/2008	Pavilion ǀ Technical base

School	District	Photos	Intervention phase	Project year	Typology
Cerco	Oporto		1	2007/2008	Pavilion ǀ Technical base
Gabriel Pereira	Évora		1	2007/2008	Pavilion ǀ Technical base
Emídio Navarro, Almada	Setúbal		2A	2008/2009	Industrial and Commercial
Lousada	Oporto		2A	2008/2009	Pavilion ǀ 3×3 blocks
Tomaz Pelayo	Oporto		2A	2008/2009	Industrial and Commercial
Carlos Amarante	Braga		2A	2008/2009	Industrial and Commercial
Caldas das Taipas	Braga	-	2A	2008/2009	Pavilion ǀ 3×3 blocks
José Saramago	Lisboa	-	2A	2008/2009	Pavilion ǀ 3×3 blocks
Carolina Michaelis	Oporto	-	1	2007/2008	JECTS Liceu

School	District	Photos	Intervention phase	Project year	Typology
Salvaterra de Magos	Santarém	-	2A	2008/2009	Pavillion I Technical base
Pedro Alexandrino	Lisboa		1	2007/2008	Pavillion I 3x3 blocks
Pedro Nunes	Lisboa		1	2007/2008	Historical Liceu
D Dinis, Lisboa	Lisboa		0	2007/2008	Pavillion I Liceu's Base

Information on project year and typology was obtained from the characterisation sheets of each school by PE.

Table 7.2 – School typologies, frequencies and relative frequencies (n = 18)

Typology	Freq.	Rel. freq. (%)
Historical Liceu	1	5.6
Industrial and Commercial	6	33.3
JCETS Liceu	1	5.6
Pavilion | 3×3 blocks	5	27.8
Pavilion | Liceu's base	1	5.6
Pavilion | Technical's base	4	22.2

The schools' typologies more common were the Industrial and Commercial (33.3%), followed by the Pavilion I 3×3 blocks (27.8%) and the Pavilion I Technical base (22.2%)

Table 7.3 – Schools' intervention phase by PE, frequencies and relative frequencies (n = 18)

Intervention phase	Freq.	Rel. freq. (%)
0	1	5.6
1	8	44.4
2A	9	50.0

Most schools were modernised in phases 2A (50 %) and 1 (44.4 %), with one pilot school rebuilt in phase 1. No schools from phase 3 were identified as expected, due to the sample characteristics (teachers from schools intervened before the school year 2010/2011).

Table 7.4 - Schools' districts, frequencies and relative frequencies (n = 22)

District	Aveiro	Braga	Leiria	Lisboa	Portalegre	Porto	Santarém	Setúbal	Évora
Rel. freq. (%)	5.0	10.0	5.0	25.0	5.0	35.0	5.0	5.0	5.0
Freq.	1	2	1	5	1	7	1	1	1

Most of the respondent's schools were from Oporto (35 %), followed by Lisbon (25 %) and Braga (10 %). The remaining were each from a different school in several districts in the country. Notice that two respondents did not identify the specific school they were in, but only its district (n = 22).

Table 7.5 – School year beginning the use of the new labs, frequencies and relative frequencies (n = 22)

School year beginning use of new labs	Freq.	Rel. freq. (%)
2008/2009	3	12.5
2009/2010	11	45.8
2010/2011	6	25.0
2011/2012	2	8.3
2012/2013	2	8.3

Most teachers began using the new labs before the school year of 2011/2012 (83.3 %), evidencing an experience in the use of the new spaces above 4 years (at the time of the questionnaire).

Teachers

Table 7.6 – Teachers' subject group, frequencies and relative frequencies (n = 24)

Subject group	Freq.	Rel. freq. (%)
Biology and Geology (520)	11	45.8
Physics and Chemistry (510)	13	54.2

The respondents were well distributed across the two subject groups, with 45.8 % in Biology and Geology and 54.2 % in Physics and Chemistry.

Table 7.7 – Teachers' gender, frequencies and relative frequencies (n = 23)

Gender	Freq.	Rel. freq. (%)
Female	21	91.3
Male	2	8.7

Most of the respondents were women (91.3 %), contrasting with 76 % in the LBFQ (Martins et al., 2002) and 71.6 % for the general teacher population of years 7-12 (DGEEC & DSEE, 2016, p. 49). This relative frequency includes teachers in the Biology and Geology subject group (520).

Table 7.8 - Teachers' age, frequencies and relative frequencies (n = 24)

Age	Freq.	Rel. freq. (%)
Between 31 and 40	4	16.7
Between 41 and 50	5	20.8
Between 51 and 60	13	54.2
More than 60	2	8.3

Most the respondents were over 50 years old (62.5 %), with an average of 51. When compared with the average age in the LBFQ for secondary Physics and Chemistry teachers, there is a clear ageing of the body of teachers, confirmed by other studies (e.g., DGEEC & DSEE, 2016, p. 37, ≥ 50 years old – 39.5% for general teacher population for years 7 to 12).

The minimum age of the respondents was 36, and the maximum was 64. The mean was 51.08 with a standard deviation of 7.35.

Table 7.9 – Teachers' number of years in teaching, frequencies and relative frequencies (n = 24)

Years in teaching	Freq.	Rel. freq. (%)
15 or less	2	8.3
Between 16 and 20	3	12.5
Between 21 and 30	12	50.0
More than 30	7	29.2

Most teachers' time in service was above 20 years (79.2 %), with a minimum of 13 and a maximum of 36 and mean of 26.95, quite above the mean of 13.1 years in the LBFQ (Martins et al., 2002, p. 6).

Table 7.10 – Teachers' number of years teaching in the present school, before the intervention, frequencies and relative frequencies (n = 24)

Years teaching in school before intervention	Freq.	Rel. freq. (%)
Less than 5	4	16.7
Between 5 and 10	7	29.2
More than 10	13	54.2

Most teachers taught in the intervened school prior to PE's intervention for more than 10 years (54.2 %), with 29.2 % between 5 and 10 years. This can provide some consistency to the comparative questions between the school before and after PE intervention approached later in this section.

Table 7.11 – Teachers' professional situation, frequencies and relative frequencies (n = 24)

Professional situation	Freq.	Rel. freq. (%)
Teacher in Pedagogical zone's permanent staff (PQZP)	2	8.3
Teacher in school/school group permanent staff (PQA/PQE)	22	91.7

Most respondents have a stable contract regime. No temporary contracted teachers were inquired mostly due to the characteristics of the sample (mostly head of facilities chosen by schools for a teacher training course, which suggested continuity in the school).

Table 7.12 - Subjects taught in the new labs, frequencies and relative frequencies (n = 24)

Subjects taught	**Freq.**
Natural Sciences years 7-9	8
Biology and Geology year 10	10
Biology and Geology year 11	10
Biology year 12	7
Geology year 12	1
Physical and Chemical Sciences years 7-9	8
Physics and Chemistry year 10	13
Physics and Chemistry year 11	13
Physics year 12	4
Chemistry year 12	6
Project Area year 12	1
Any year/subject in Technological/Professional courses	2

The subjects more frequently taught in the new labs were years 10 and 11 Science (both PC and BG, 13 and 10 respectively). Years 7 to 9 Science are the next most frequent subject taught in the labs (8 in both subjects). Physics year 12 (4) and Geology year 12 (1) and any year or subject in Technological or Professional courses (2) were the least common subjects taught in the new labs, as was the extinct AP year 12 (1).

7.5.2 Use of the new labs

In this section, teachers were presented with 7 situations of the use of the new labs, focusing on a specific element of the SLS. The aim was to understand:

1. The differences between the planned and implemented model of the SLS (RQ 3);
2. The actual use of the specific elements in teachers' daily activities, and its relation to the envisioned activities in the conceptual model of the SLS (RQ 2.1);
3. The attitudes teachers had towards that envisioned use and the reasons behind the kind of use given (RQ 1 and 1.1).

These 7 situations were illustrated using Google Sketchup frames with Microsoft OneNote drawings over those snapshots, with a short description giving some detail to the illustration. The title of each set of questions defined the envisioned activity using the element:

1. Collaboration with students in the teaching wall;
2. Improvised use, during an activity, of equipment and other materials in the teaching wall or transparent storage modules;

3. Change of configuration of movable benches according to type of activity;
4. Students working autonomously in the prep room during an activity in the lab;
5. Casual observation of colleagues during activity in their lessons in an adjacent lab;
6. Use of honeycombs to store students' bags and coats in the beginning of lessons;
7. Exhibition of students' work in the lab.

Other elements in use were not included in the questionnaire (washing module, help point, fume cupboard, etc.) to achieve a balance in response time. The criteria of choice were mostly based on visits to approx. 25 new schools since 2008, in which these elements had a more consistent and predictable use (washing module in the lab with students cleaning the materials after the practical activity, non-integrated help points, with scattered active safety equipment and first aid kit, or fume cupboards either in the prep room or the lab.

Collaboration with students in the teaching wall

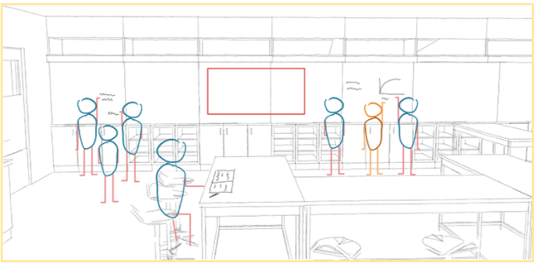


Figure 7.3 – Students collaborating in the teaching wall

The teaching wall, besides its uses as a projection and writing area for the teacher to support diverse teaching activities, can also be used for storing materials useful across multiple lessons and for exhibiting equipment and objects in the overhead compartments. One of its envisioned uses was as an extended area for students' collaboration, reducing the room front control by the teacher and providing more opportunities for students to act, either by presenting results to the class, preparing practical activities, analysing data, peer-instructing their peers, designing experiments, planning a project, etc.

Table 7.13 – Presence of teaching wall in labs, frequencies and relative frequencies (n = 24)

Teaching wall	Freq.	Rel. freq. (%)
Not present	1	4.2
Not sure	1	4.2
Partially present	1	4.2
Present	21	87.5

The teaching wall was identified by most of the respondents as being present or partially present (91.7 %) in the new labs. One of the teachers was not sure if the labs had a teaching wall and another referred that the labs didn't have one.

Table 7.14 – Frequency of use of teaching wall as students' collaboration area and relative frequencies (n = 22)

Frequency of use of teaching wall as students' collaboration area	Freq.	Rel. freq. (%)
Rarely (typically once or twice each term)	2	27.3
Occasionally	6	9.1
Very frequently (in every or almost every group activities)	14	63.6

Most of the respondents affirm that the teaching wall is very frequently used in this sense (63.6 %), with 27.3 % using it rarely in this way and 9.1 % only occasionally.

Table 7.15 – Main reason for frequency of use of teaching wall as students' collaboration area and relative frequencies (n = 22)

Main reason for frequency of use of teaching wall as students' collaboration area	Freq.	Rel. freq. (%)
I try to share the class front with students	16	72.7
It's not an activity typical of my teaching style	1	4.5
Students only work in group in benches	2	9.1
Other	3	13.6

Most teachers try to share the lab front with students (72.7 %) with only three offering reasons for not using the teaching wall in this way. Other reasons justifying the frequency of use are "to share results between groups of students", "to synthesise themes" and "to frequently give status reports during lessons".

Improvised use, during an activity, of equipment and other materials in the teaching wall or storage modules

The transparent storage modules either in the teaching wall or below the side benches can provide opportunities for coordinating activities by facilitating access to objects and materials that provide concrete referents for students' meaning making across knowledge domains. This was the proposition that guided the implementation of this element of the model of SLS, combined with the use of the lab not only for practical but also for theoretical lessons.

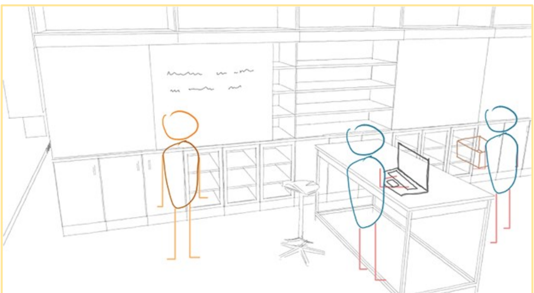


Figure 7.4 – Teacher using the teaching wall, while a student uses his/her laptop and one of the students gets some material from the storage space in the teaching wall

Table 7.16 – Presence of transparent storage modules in labs, frequencies and relative frequencies (n = 24)

Transparent storage modules	Freq.	Rel. freq. (%)
Not present	3	12.5
Partially present	8	33.3
Present	13	54.2

Most teachers identify transparent storage modules in the new labs, partially (33.3 %) or totally present (54.2 %). In 16.7 % of schools, transparency in storage modules was not implemented.

Table 7.17 – Frequency of improvised use, during an activity, of objects and materials in the storage modules in the teaching wall and below side benches, frequencies and relative frequencies (n = 24)

Frequency of improvisation of activity with objects and materials	Freq.	Rel. freq. (%)
Rarely (typically once or twice per term)	4	16.7
Occasionally	14	58.3
Very frequently (at least twice a month)	6	25.0

58.3 % of teachers only occasionally improvise activities with equipment or materials in the storage modules, with 25.0 % doing this very frequently and 16.7 % rarely.

Table 7.18 – Main reasons for frequency of improvised used, during an activity, of objects and materials in the storage modules, frequencies and relative frequencies (n = 24)

Main reason for frequency of improvisation	Freq.	Rel. freq. (%)
Visibility of daily use materials and equipment facilitates improvisation	13	56.5
In the teaching wall and storage modules closer to the teacher are not stored useful equipment and materials for this kind of use	3	13.0
It's not common to improvise activities I did not plan	1	4.3
There is no transparency in most of the storage modules	1	4.3
Other	5	21.7

The main reasons presented by teachers for frequency of improvisation in the use of objects and materials during an activity are that visibility to daily use' materials and equipment facilitates its integration during a lesson (56.5 %) and that, due to organisational aspects of the lab, in these storage modules are not stored useful equipment for this kind of use (13.0 %). Other reasons put forth are that activities in the lab are exclusively planned in advance (8.3 %). In one of the comments, as all the material is stored in the modules under the side benches, keys of the modules are mentioned as a barrier as each has its own key, stored in a keyring outside the lab.

Change of configuration of movable benches according to type of activity

One of the key elements differentiating the new SLS model from previous models for schools' Science spaces in Portugal was the flexibility of use of the lab for different teaching and learning activities, not just canonical practical Science activities. This was achieved by moving fixed benches for the sides of the labs, integrating the water and electrical infrastructure, and in the middle placing movable benches, with the same height of the side benches, that allowed easy reconfiguration of the space according to the type of activity, either seated or standing.

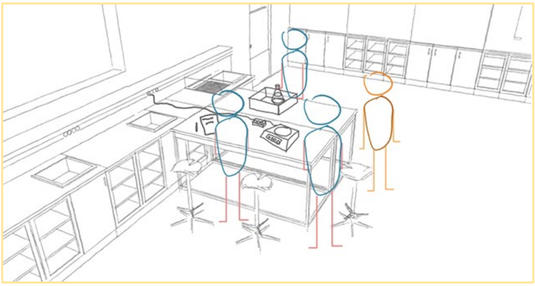


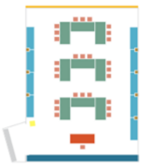
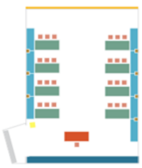
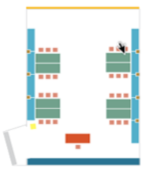
Figure 7.5 – A possible configuration for a practical activity, with two movable benches positioned against the side benches and students around, seated or standing

Table 7.19 – Presence of movable benches in labs, frequencies and relative frequencies (n = 24)

Movable benches	Freq.	Rel. freq. (%)
Present	24	100.0

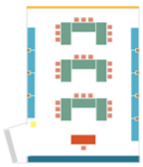
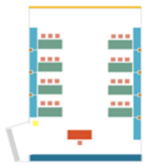
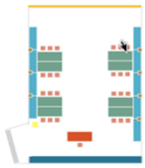
Every lab has movable benches.

Table 7.20 – Configurations of movable benches used in practical lessons, frequencies and relative frequencies (n = 24)

Rel. freq. (%)	4.2	41.7	25.0	29.2
Freq.	1	10	6	7
Configuration used in practical lessons	A 	C 	D 	Other

The most frequent configurations used in the labs for practical lessons are C (41.7 %) and D (29.2 %), with movable benches positioned either individually or in groups of 2 against the side benches, or a variation of both, with space left between the movable and side benches.

Table 7.21 – Configurations of movable benches used in theoretical lessons, frequencies and relative frequencies (n = 24)

Rel. freq. (%)	4.2	45.8	8.3	41.7
Freq.	1	11	2	10
Configuration used in theoretical lessons	A 	C 	D 	Other

The most common configuration used by teachers in theoretical lessons is mostly C (45.8 %) and a variation of it (41.7 %), with space left between the movable and side benches.

Table 7.22 – Frequency of change of configuration of movable benches according to type of activity, frequencies and relative frequencies (n = 24)

Change of configuration according to type of activity	**Freq.**	**Rel. freq. (%)**
Never	2	8.3
Rarely (typically once or twice per term)	4	16.7
Occasionally (only in practical lessons)	16	66.7
Very frequently (most/all lessons)	2	8.3

Most teachers only occasionally change the lab configuration, and only in practical lessons (66.7 %). From the two previous answers, a standard row configuration is the most common, in both practical and theoretical lessons.

Table 7.23 – Main reasons for frequency of change of configuration of movable benches according to type of activity, frequencies and relative frequencies (n = 24)

Main reason for frequency of changing configuration according to type of activity	Freq.	Rel. freq. (%)
Before next class, benches have to be put in the original configuration	2	8.3
Benches are too heavy to allow a quick rearragement	4	16.7
I prefer fixed benches in the center, as students are always facing the teacher	2	8.3
I try, whenever possible, to adapt space to the type of activity	12	50.0
Other	4	16.7

From teachers that occasionally change the lab configuration (66.67 %), 62.5 % refer that they try, whenever possible, to adapt space to the type of activity, as do the teachers that very frequently change this configuration (8.3 %). The reasons advanced for never or rarely changing it are the need to replace benches in the original configuration before next class (12.5 %) and the heaviness of the benches (2 cases and 2 more on the comments to this question). Two teachers considered the fixed benches at the centre of the lab as the best option, as students are always facing the teacher. Two teachers also considered the quality of the benches not adequate to being moved on a daily basis.

Students working autonomously in the prep room during an activity in the lab

The transparency between the pair of labs and the interleaved prep room was intended to allow lines of sight between teachers, students and operational assistants. This could be helpful if during an activity the teacher must go to the prep room, request assistance from a technician if present, send students to the prep room to get some material or do a certain procedure, and so on.

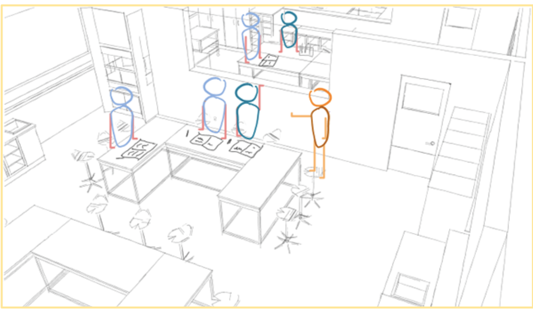


Figure 7.6 – Teacher working with students in the lab while some of them are in the prep room

Table 7.24 – Transparency between the lab and prep room, frequencies and relative frequencies (n = 23)

Transparency between lab and prep room	Freq.	Rel. freq. (%)
Not present	11	47.8
Partially Present	4	17.4
Present	8	34.8

The transparency is not present in 44.44 % of the schools and partially present in only 16.67 %. 38.89 % of the schools have transparency between the lab and prep room.

Table 7.25 – Frequency of students going autonomously to the prep room, during an activity in the lab, frequencies and relative frequencies (n = 23)

Frequency of students going autonomously to the prep room	Freq.	Rel. freq. (%)
Never	4	17.4
Rarely (typically once or twice per term)	11	47.8
Occasionally	5	21.7
Very frequently (most/all practical lessons)	3	13.0

Students don't usually go autonomously to the prep room, during an activity in the lab (65.2 % never or rarely go), with only with three teachers allowing very frequent access. This happens in two schools without transparency and in one with only partial transparency.

Table 7.26 – Main reasons for frequency of students going autonomously to the prep room, during an activity in the lab, frequencies (n = 24)

Main reason for frequency of students going autonomously to the prep room	Freq.
Not all of my students are sufficiently autonomous to do it	3
There is no transparency to the prep room	7
Transparency to the prep room was covered to provide privacy	1
Whenever possible, I try to develop my students' autonomy	6
Other	5

The main reasons advanced by teachers for the frequency of letting students go autonomously to the prep room are the lack of transparency (29.17 %), the development of their students' autonomy (n = 6), the level of autonomy of students (12.5 %) or that the transparency to the prep room was covered to provide privacy (4.17 %), something I have seen in some schools. Other reasons pointed out are that all the required material is already in the lab in trays, that there is no need for transparency as activities take place in the lab, or that they only go to the prep room if the use fume cupboard is required.

Casual observation of colleagues during activity in their lessons in an adjacent lab

The transparency between adjacent labs, either side by side or through the interleaved prep room was intended to allow lines of sight between teachers and students, if standing.

Figure 7.7 – Lessons in adjacent labs are visible through transparency between spaces

This could provide opportunities for observing colleagues' practices and contribute to a culture of professional exchange and transparency.

Table 7.27 – Transparency between labs, frequencies and relative frequencies (n = 23)

Transparency between labs	Freq.	Rel. freq. (%)
Not present	12	52.2
Partially present	3	13.0
Present	8	34.8

Transparency between adjacent labs is present for 34.8 % of respondents. More than half, however, do not report this feature (52.2 %).

Table 7.28 – Frequency of exchange of ideas with colleagues about an activity casually observed in his/her lessons, frequencies and relative frequencies (n = 23)

Frequency of exchange of ideas with colleagues about an activity casually observed in his/her lessons	Freq.	Rel. freq. (%)
Never	2	8.7
Rarely (typically once or twice per term)	6	26.1
Occasionally	12	52.2
Very frequently (every week)	3	13.0

Exchange of ideas between colleagues about an activity casually observed in a lesson is occasional (52.2 %) or rare (26.1 %), with only 3 teachers reporting very frequent exchanges (every week, 13.0 %).

Table 7.29 – Main reasons for frequency of exchange of ideas with colleagues, frequencies (n = 24)

Main reason for frequency of exchange of ideas with colleagues	Freq.
It's an opportunity to observe our colleagues without the weight of assessment	1
It's common for colleagues to enter the lab to search or store material, ask questions or even observe	11
There is no transparency to the adjacent lab or there is no visibility due to structural reasons	6
The transparency to the adjacent lab is covered with furniture or other kind of opaque material	1
Other	3

45.8 % of teachers report that it's common for colleagues to enter the lab to search or store material, ask questions or even observe. 54.17 % of teachers refer as the main reason for the frequency of exchange the lack of transparency between adjacent labs. Three teachers mention in the comments that at least some colleagues don't feel comfortable being observed in lessons, even if casual. One teacher also refers that the school has a collaborative culture and another that, due to the high number of students in classes, co-teaching is starting to take place.

Use of honeycombs to store students' bags and jackets in the beginning of lessons

Honeycombs were intended to free lab space and benches from clutter, improving safety and facilitating circulation, particularly during practical activities.

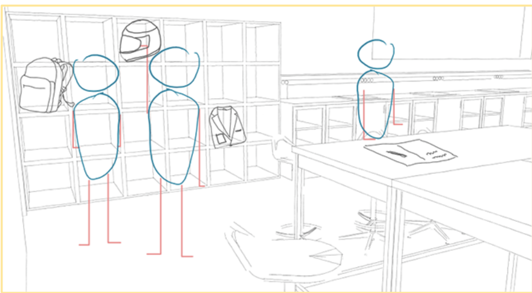


Figure 7.8 – Illustration of students using the honeycombs to store bags and jackets

The following table resumes the frequencies and relative frequencies of the presence of honeycombs in the respondents' schools.

Table 7.30 – Honeycombs, frequencies and relative frequencies (n = 23)

Honeycombs	Freq.	Rel. freq. (%)
Not present	3	13.0
Present	20	87.0

Honeycombs are present in most schools, with teachers from two schools reporting them inexistent.

Table 7.31 – Frequency of use of honeycombs to store students' bags and jackets in the beginning of lessons, frequencies and relative frequencies (n = 23)

Frequency of use of honeycombs to store students' bags and jackets in the beginning of lessons	Freq.	Rel. freq. (%)
Never	3	13.0
Occasionally (only in practical lessons)	4	17.4
Very frequently (All/most lessons)	16	69.6

69.6 % of teachers use the honeycombs very frequently in all or most lessons, with 17.4 % of teachers only using them during practical lessons and 13.0 % reporting never using them.

Table 7.32 – Main reason for frequency of use of honeycombs to store student's bags and jackets, frequencies and relative frequencies (n = 23)

Main reason for frequency of use of honeycombs to store students' bags and jackets	Freq.	Rel. freq. (%)
I don't feel the need to use the honeycombs	1	4.3
There are no honeycombs	2	8.7
The honeycombs are in an area without visual control with the risk of theft	1	4.3
Its use facilitate circulation in the lab and uncluttered benches	17	73.9
Other	2	8.7

Most teachers concur that using the honeycombs facilitates circulation in the lab and keeps benches uncluttered (73.9 %). Two teachers mention that students don't like to leave their bags.

Exhibition of students' work in the lab

Areas for exhibiting students' work were considered, mostly on shelves on the sides of the lab or on the top compartments of the teaching wall.

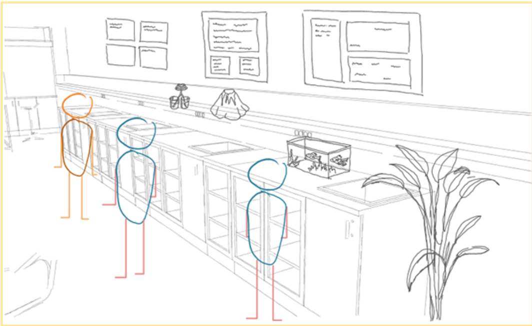


Figure 7.9 – Illustration of student's work exhibited in shelves

Table 7.33 – Shelves, frequencies and relative frequencies (n = 23)

Shelves	Freq.	Rel. freq. (%)
Not present	2	8.7
Present	21	91.3

Table 7.34 – Frequency of exhibition of students work in the lab, frequencies and relative frequencies (n = 23)

Frequency of exhibition of students' work in the lab	Freq.	Rel. freq. (%)
Never	2	8.7
Rarely	3	13.0
Occasionally (once a year)	8	34.8
Very frequently (at least twice a year)	10	43.5

Most teachers report that they very frequently (45.5 %) or occasionally (34.8 %) exhibit students' work in the lab.

Table 7.35 – Main reasons for frequency of use of shelves for exhibiting students' work in the lab, frequencies and relative frequencies (n = 23)

Main reason for frequency of use of shelves for exhibiting students' work in the lab	Freq.	Rel. freq. (%)
As labs are used by many teachers and students, I can't coordinate this task	3	13.0
It's an appreciation of student's work and makes space more welcoming and participated	14	60.9
There are no shelves	1	4.3
Shelves are not adequate to exhibit students work	2	8.7
Shelves are occupied by other materials	2	8.7
Other	1	4.3

The main reasons for the frequency of use of shelves for exhibiting students' work in the lab are as a way of appreciation of their work and of making the space more welcoming and participated (60.9 %), with several reasons pointing to an issue of management (shelves occupied by other materials 8.7 %, use of labs by many teachers 13.0 %) or its characteristics (8.7 %).

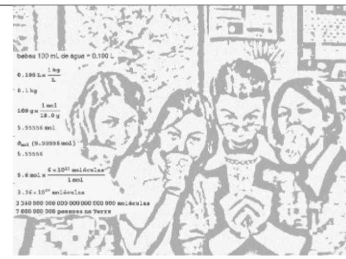
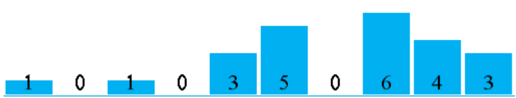
7.5.3 Activities taking place in the Science Learning Studios

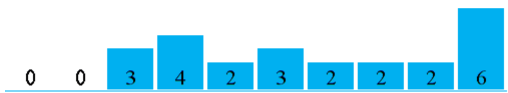
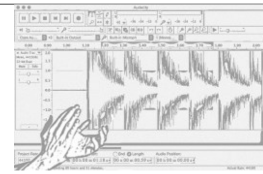
To understand what kind of activities are taking place in the SLS, besides the uses given to the elements of the SLS in the previous section, a section of the survey included 9 situations, 3 per mode of lesson (project/open enquiry, theoretical, practical). Each situation intended to reveal two aspects of activity: engagement of students interoceptive, exteroceptive and proprioceptive modalities and coordination between scale domains of activity (sensory-perceptual ↔ conceptual or conceptual ↔ meta-conceptual. In this sense, each situation required of teachers to respond to a concrete example of a lesson activity, with a more abstract description that could facilitate transfer to individual practice, defining the degree of alignment with their own teaching practice of these same situations. Illustrations and descriptions were prepared from observations collected in the case studies.

After each table resuming the data gathered, a brief analysis will be made.

Theoretical lessons

Table 7.36 – Frequencies for degree of agreement with 3 types of coordinating activities in theoretical lessons (n = 24; the slider allowed 10 positions)

Frequencies	Type of activities
A1 	 **Concrete description:** Students, in small groups, are invited to drink glasses of water of different sizes. The teacher then asks them “How many water molecules have you just drank?” then supporting groups in their calculations **Abstract description:** Students, in small groups, collaborate in solving qualitative and quantitative problems. These problems can approach conceptual numerical or computational aspects, departing from an imagined situation or from students’ everyday life that is motivational
A2 	 **Concrete description** A student demonstrates the situation described in a worksheet about kinetics in an inclined plane, using a Lego car and her notebook. Each student then proposes answers to one of the questions, then discussed in the group until a consensus is achieved. The consensual answer is then communicated to the large group, and the teacher provides feedback

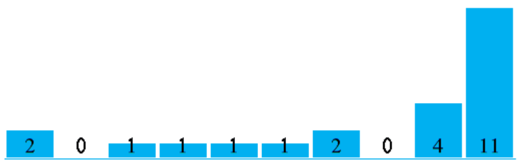
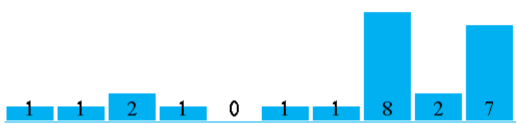
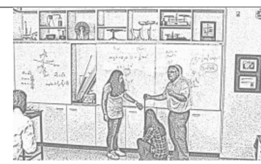
Frequencies	Type of activities
	Abstract description In small groups, from a situation suggested by the teacher, students peer instruct each other, discussing until obtaining a consensual answer. Answers are then communicated to the class and the teacher provides feedback
A3  	 **Concrete description** The teacher asks a student how many hand claps can she give in one second. The student tries to clap as fast as she can, while the teacher records the clapping with a microphone and an audio application on the computer. The captured data are then analysed in a large group setting, introducing the hertz unit and the concept of inverse proportionality **Abstract description** Students are invited to exemplify with the body abstract concepts, e.g., velocity, acceleration, angle
	

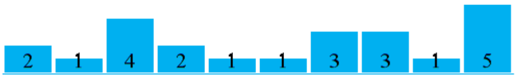
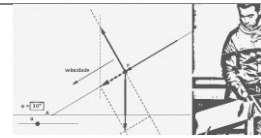
The chosen situations in theoretical lessons were considered to reflect the coordination between sensory-perceptual and conceptual scales of students' activity, providing explicit links between both. It was also considered that all reflected coordination of multiple students' modalities, interoceptive (related to positive emotions and feelings, for both the student that was described but also for the remaining students who watched), exteroceptive (engaging external senses such as sight, taste, hearing, touch) and proprioceptive (using multiple body dispositions).

According to the data gathered, in theoretical lessons, tasks supporting coordination between scales of activity and multiple modalities are not the consensual practice among respondents in the three situations presented. 45.8 %, 54.2 % and 41.7 % of the teachers, respectively to situations A1, A2 and A3, positioned themselves in positions 8, 9 and 10 of the scale, stating that the activity was very much aligned with their teaching practice.

Practical lessons

Table 7.37 – Frequencies for degree of agreement with 3 types of coordinating activities in practical lessons (n = 24; the slider allowed 10 positions)

Frequencies	Types of activities
B1 	 **Concrete description** To register their work, students take photos of the procedures during the practical work, using later the photos in a report and during the presentation of their work to the class, which are then analysed by teachers and the large group **Abstract description** Students take photos or make videos of the practical activities, giving a personal touch to the final report, presentation or video, providing snapshots of practice for analysis and reflection
B2 	 **Concrete description** Students participate in an interactive demonstration of the teacher to the large group, the free fall of a tennis ball, measuring the distance with a tape measure and a smartphone chronometer, predicting, testing and discussing results **Abstract description** Students observe/participate in interactive demonstrations by the teacher, using lab equipment or everyday objects. In small groups, they discuss and make predictions of the results of the demonstrations

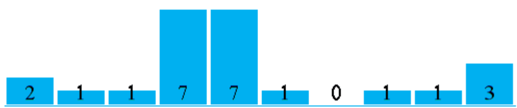
Frequencies	Types of activities
B3 	 **Concrete description** From a model of an inclined plane exercise simulated with a table, a golf ball and an extensible pointer by a group of students, a student represents the model in a geometry software for the large group **Abstract description** From the manipulation of objects or their own body, students schematically represent a conceptual model, either with software, materials or paper and pencil
	

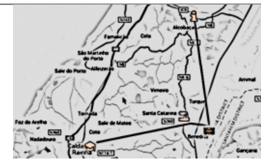
The chosen situations in practical lessons were considered to reflect coordination between sensory-perceptual and conceptual or conceptual and meta-conceptual scales of students' activity, providing explicit links between scales. It was also considered that all reflected coordination of multiple students' modalities, interoceptive (related to positive emotions and feelings, for both the student that was described but also for the remaining students who observed), exteroceptive (engaging external senses such as sight, hearing, touch) and proprioceptive (using multiple body dispositions).

According to the data gathered, in practical lessons, tasks supporting coordination between students' scales of activity and multiple modalities are for a larger number of teachers, more aligned with their teaching practice, except in situation B3. 62.5 %, 70.8 % and 37.5 % teachers positioned themselves in positions 8, 9 and 10 of the scale, respectively to situations B1, B2 and B3, stating that the activity was very much aligned with their teaching practice. The difference observed in situation B3 can have multiple explanations, such as the limited use of educational software by teachers or exploration of the body to represent concepts.

Project/Open enquiry lessons

Table 7.38 – Frequencies for degree of agreement with 3 types of coordinating activities in project/open enquiry lessons (n = 24; the slider allowed 10 positions)

Frequencies	Types of activities
C1  	 **Concrete description** Students decide to study the environmental impact of an important industry close to the school. The teacher supports the study of the quality of the effluent of the factory, analysing the discharge in a local water stream **Abstract description** Students initiate authentic investigations from their own interests and meaningful for themselves, the school and the community. They don't know from the start how the activity will develop, and learn what is required to achieve their goal, working collaboratively with the teacher, experts and community members
C2  	 UMA AVENTURA - UM PROJECTO LABORATÓRIOS ABERTOS **Concrete description** The data from the investigation described earlier is published in a local newspaper, calling the attention of the community to the environmental problem **Abstract description** Products of authentic investigations by students are communicated to the community, with potentially significant social changes

Frequencies	Types of activities
C3 	 **Concrete description** The authentic investigation takes place in several places, in a research centre of a higher education institution, the local factory, in the water stream or in the town hall **Abstract description** The authentic investigations made by students takes place in several places, involving diverse interactions with objects, people and institutions
	

The chosen situations in project/open inquiry lessons were considered to reflect coordination between sensory-perceptual, conceptual and meta-conceptual scales of students' activity, providing explicit links between both.

According to the data gathered, in project/open enquiry lessons, tasks supporting coordination between students' scales of activity are not usually aligned with their teaching practice. 20.8 %, 33.3 % and 29.1 % of the teachers positioned themselves in positions 8, 9 and 10 of the scale, respectively to situations C1, C2 and C3, stating that the activity was very much aligned with their teaching practice.

Project/open inquiry lessons, without proper time in the curricula, are usually developed in the practical component of the scientific subject (62.5 %) and club or extra-curricular activity (33.3 %). It is predictable that the time devoted to this kind of projects is marginal due to time limitations.

Table 7.39 – Frequency of contexts for developing projects and open enquiry activities (n = 24)

Contexts for development of projects and open inquiry activities	Freq.
Practical component of my scientific subject	14
Club or extra-curricular activity	8
Project Area in year 12	4
Project Area in years 7 to 9	2
Technological or Professional courses	2
Other	5

Use of labs for theoretical lessons

Table 7.40 – Frequency of use of labs for theoretical lessons, frequencies and relative frequencies (n = 24)

Frequency of use of labs for theoretical lessons	Freq.	Rel. freq. (%)
Rarely (typically once or twice per term)	9	37.5
Occasionally	10	41.7
Very frequently (most/all lessons of that type)	5	20.8

Labs are occasionally (41.7 %) or rarely (37.5 %) used for theoretical lessons, with only 20.8 % of teachers reporting their very frequent use for this type of lessons.

Table 7.41 – Main reasons for frequency of use of labs for theoretical lessons, frequencies and relative frequencies (n = 23)

Main reason for frequency of use of labs for theoretical lessons	Freq.	Rel. freq. (%)
I don't feel the need of using the labs for this type of lessons	3	12.5
Labs don't have conditions to accomodate an entire class	2	8.3
Labs were allocated to all Science lessons	2	8.3
The occupation rate doesn't allow use of labs for this type of lessons	3	12.5
Whenever possible, I try to have non-practical lessons in the labs, as I favour the use of materials and equipment	9	37.5
Other	5	20.8

In only 11.1 % of schools were labs attributed to both theoretical and practical lessons. 37.5 % of teachers report that whenever possible, they try to have non-practical lessons in the labs, as they favour the use of materials and equipment in those lessons.

Duration of teaching of AP year 12

Table 7.42 – Duration of teaching of AP year 12, frequencies and relative frequencies (n = 24)

Duration of teaching of AP (years)	Freq.	Rel. freq. (%)
None	19	79.2
1 year	3	12.5
2 years	1	4.2
3 years	1	4.2

Only 20.83 % of teachers taught this subject, most for 1 year, and in some cases for 2 to 3 years.

Quality of experience in teaching AP year 12

Table 7.43 – Quality of experience in teaching AP year 12, frequencies (n = 5)

Most teachers (80.0 %) had a very stimulating experience in teaching this subject, with one teacher only having a slightly stimulating experience.

Reasons justifying quality of experience in teaching AP year 12

Table 7.44 – Main reasons justifying the quality of experience in teaching of AP year 12, frequencies (n = 5)

Main reasons justifying quality of experience in teaching of AP	**Freq.**
It was not a subject that I have chosen to teach and it was not very meaningful	1
The subject's features made possible the development of meaningful activities, for me and for the students	3
The subject's features made possible the development of activities that evidence to students the techno-scientific aspects and the nature of science	4
The subject's features made possible the development of activities in collaboration with people and institutions inside and outside of school	3
I dont' consider this subject relevant in the curriculum	1

The subjects' features were pointed out by teachers as opportunities for developing activities that evidenced to students the technoscientific aspects and the nature of Science (80.0 %), that are meaningful (60.0 %) and with collaboration with people and institutions inside and outside of school

(60.0 %). One of the teachers responded that it was not a subject that she chose to teach and was not very meaningful. This teacher also did not consider it AP a relevant subject in the curriculum.

7.5.4 Parque Escolar's intervention

One of the assumptions of PE's intervention was the involvement of schools (Parque Escolar, 2010) in the rebuilding process, either in the planning, construction and post-occupancy stages.

Table 7.45 – Kind of involvement in PE's intervention, frequencies (n = 24)

Involvement in PE intervention	Freq.
I helped prepare a proposal for the new school's science spaces	5
I supported or was part of the Head teacher's team during the process	4
I participated regularly in meetings with Parque Escolar	2
I didn't have any kind of participation	12
Other	3

The involvement of the respondents during PE's intervention was mostly inexistent for half of the respondents (50.0 %), followed by the participation in a school team that prepared a proposal for the new school's Science spaces (20.8 %) or the support or membership on the head teacher's team during the intervention (16.7 %). A minority participated in meetings with PE (8.3 %) or in minimal interactions, as stated in the comments to this question.

Table 7.46 – Schools and number of labs before and after PE's intervention (n = 18)

School	Before PE's intervention	After PE's intervention
Caldas das Taipas	2.0	7.0
Carlos Amarante	4.0	8.5
Carolina Michaelis	4.0	7.0
Cerco	3.5	4.5
D. Dinis	6.0	4.0
Domingos Sequeira	4.5	6.5
Dr. Manuel Gomes Almeida	6.0	9.0
Emídio Navarro	4.0	6.0
Gabriel Pereira	3.0	5.0
João Gonçalves Zarco	4.0	5.0
José Saramago	3.0	6.0
Lousada	6.0	8.0
Pedro Alexandrino	2.0	3.0
Pedro Nunes	4.0	5.0
Ponte de Sôr	4.0	5.0
Rocha Peixoto	2.0	6.0
Salvaterra de Magos	5.0	7.0
Tomaz Pelayo	2.0	4.0

Most schools increased the number of labs after PE's intervention. The mean increase in number of labs was 70.7 %, with a maximum of 250% and in one case, with the loss of one-third of the original labs, from 6 to 4 (D. Dinis, a pilot school). In the case of Carlos Amarante, Cerco, Emídio Navarro and Domingos Sequeira, where teachers from both subject groups responded (PC and BG), the number of labs was averaged (sometimes averaging 0.5 labs).

Comparison of general conditions before and after Parque Escolar's intervention

The rebuilding programme implemented a new functional programme that had not only pedagogical but also physical improvements.

Table 7.47 – Comparison of general conditions before and after PE's intervention, frequencies for several school spaces in the following semantic differential with 10 positions

	1	2	3	4	5	6	7	8	9	10
School library (n = 24)	2	0	1	0	2	0	3	3	3	10
Living spaces (n = 24)	0	0	2	2	4	3	0	1	4	8
Specialised spaces (n = 24)	0	0	0	2	2	2	1	3	6	8

General teachers’ room (n = 24)	Science teachers’ workspace (n = 24)	Storage areas (n = 24)
0 1 1 0 3 3 1 3 1 11	0 1 0 0 5 4 1 3 1 9	0 2 1 0 3 1 3 4 5 5
Classrooms (n = 24)	**Labs (n = 24)**	**Prep rooms (n = 24)**
1 0 1 1 2 4 3 5 1 6	1 2 0 0 2 1 1 5 7 5	0 0 0 0 4 4 2 3 0 11

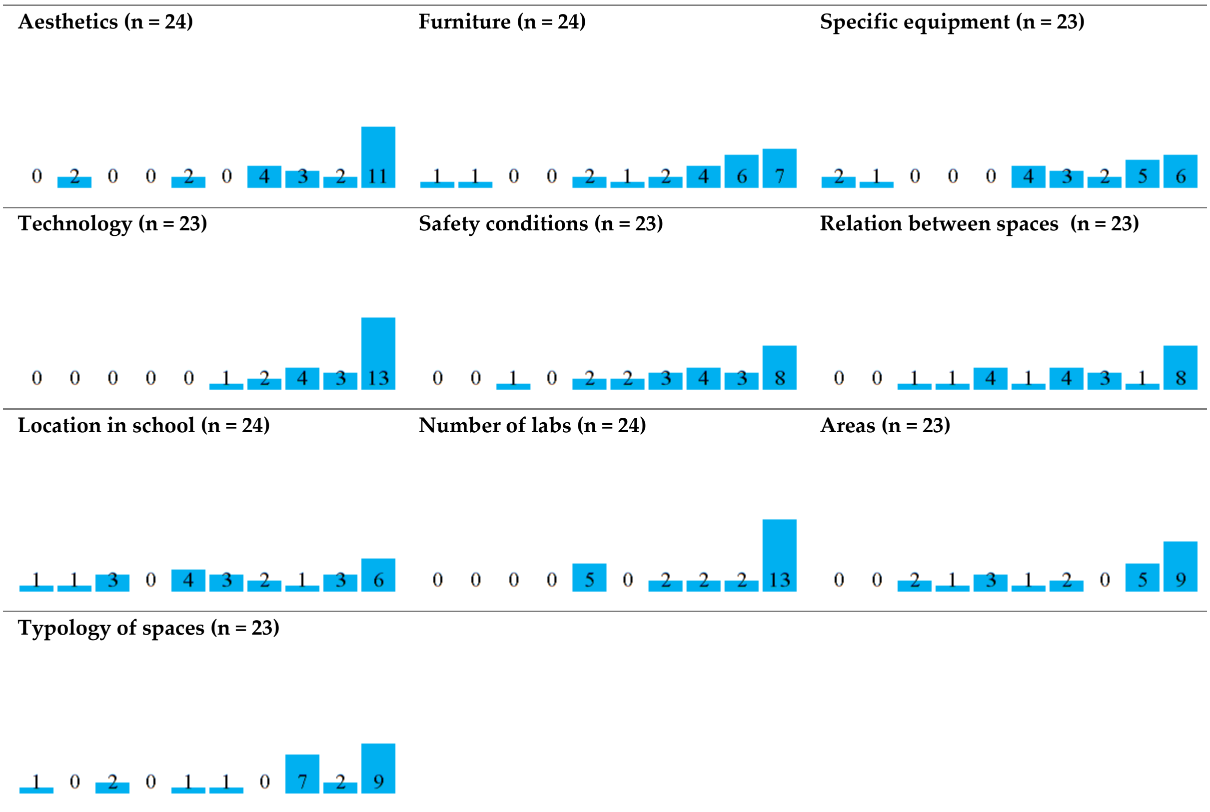
In general, most respondents compared positively the new school with the previous one. If the positions 6 to 10 are considered as improvements, the order of spaces where general conditions after PE’s intervention were perceived as successful are:

1. Prep rooms (83.3 %);
2. Specialised spaces, such as canteen, bar, auditorium (83.3 %);
3. Labs (79.2 %);
4. Classrooms (79.2 %);
5. School library (79.2 %);
6. General teachers’ room (79.2 %);
7. Storage areas (75.0 %);
8. Science teachers’ working space (75.0 %);
9. Living spaces (66.7 %).

Comparison of Science spaces and conditions before and after Parque Escolar’s intervention

Table 7.48 - Comparison of Science spaces and conditions before and after PE’s intervention – Frequencies in the following semantic differential with 10 positions

Ventilation and air temp. (n = 24)	Acoustics (n = 23)	Lighting (n = 24)
2 0 1 2 7 4 1 1 5 1	0 2 0 0 1 0 2 5 1 12	0 2 1 0 2 1 2 4 2 10



In general, the evolution between Science spaces and conditions is positive. The comparisons made by teachers suggests a ranking of improvements after PE's intervention, from higher to lower, aggregating positions 6 to 10 in the classification scale:

1. Technology (100 %);
2. Acoustics (87.0 %);
3. Safety conditions (87.0 %);
4. Aesthetics (83.3 %);
5. Lighting (70.2 %);
6. Typology of spaces (82.6 %);
7. Specific equipment (82.6 %);
8. Number of labs (79.2 %);
9. Furniture (79. 2 %);
10. Relations between Science spaces (73.9 %);
11. Areas (73.9 %);
12. Location in school (63.0 %);
13. Ventilation and air temperature (50.0 %).

The most contended conditions are ventilation and air temperature, followed by location in school, space areas and relations between spaces.

7.5.5 Organisation and management of the Science Learning Studios

This study had as a goal understanding organisational and managerial options taken by schools concerning the new labs, such as lab specialisation, attribution to theoretical lessons, uses beyond lessons, or support mechanisms to the daily functioning of the SLS.

Lab specialisation

Table 7.49 – Options taken for labs specialisation (n = 24, as teachers from the same school were all from different subject groups)

Options taken for lab specialisation	Freq.
One pair of labs and prep room for each speciality (e.g. one pair for Chemistry, another pair for Biology)	13
One pair of labs and prep room for each subject (e.g. one pair for Chem. and Phys., another for Bio. and Geo.)	13
Most/all labs are considered Polyvalent for scientific subjects in years 7 to 9	2
Most/all labs are considered Polyvalent for secondary level scientific subjects	3
One laboratory or pair of laboratories and prep room for scientific subjects in years 7 to 9	2
Labs are also used for non-scientific subject areas	2
Other	3

The most common options in labs specialisation were the attribution of one pair of labs and prep room for each scientific speciality (e.g., one pair for Chemistry, another for Physics, etc., 54.16 %) or the attribution of one pair of labs and prep room for each subject (e.g., one pair for Physics and Chemistry, another for Biology and Geology, 54.2 %). In two cases where the secondary school had also an offer for years 7 to 9, the option was for establishing a Polyvalent lab for these classes. In two cases, labs were also used for non-scientific subjects.

Use of labs beyond lessons

Table 7.50 – Uses of the new labs beyond Science lessons (n = 24, as teachers from the same school were all from different subject groups)

Uses beyond science lessons	**Freq.**
National examinations' school team	2
Group meetings	14
Department meetings	3
Support to open days (e.g. Science or Health Week/Day)	19
Support to students' projects	12
Support to science clubs and similar	17
Professional development	11
Other	1

The new labs are commonly used to support open days (e.g., Science or Health Week/Day, 79.2 %), Science clubs or similar (70.8 %), group meetings (58.3 %), students' projects (50.0 %) and professional development (45.8 %). There were some cases of use by the national examinations' school team, the enrolments' team or department meetings.

Type of support in the organisation and management of labs

Table 7.51 – Type of support in organisation and management of the labs (n = 24, as teachers from the same school were all from different subject groups)

Type of support in organisation and management	**Freq.**
Operational assistant providing basic support to the labs	10
Operational assistant, with training and expertise, supporting the labs	5
Digital inventory	7
Yearly budget	3
Organisation and management plan, with a well defined worflow	1
System for chemicals storage	7
System of chemicals labelling	4
System of waste management	1
Other	1

Almost half of teachers' (41. 7 %) report having an operational assistant providing basic support to the labs, with close to a fifth (20.83 %) referring a specialised assistant. The role of lab technician, already extinct in the legislation, still endures in some schools. Instruments such as digital inventories or a system for chemical storage are reported by 29.2 % of teachers, with other mechanisms that support an efficient workflow existing in only a minority of schools. Only one school reports having an organisation and management plan for the labs, with a well-defined workflow.

7.5.6 Detailed characterisation of teachers

In this detailed characterisation of teachers, I wished to gain insights on the professional culture of the inquired teachers, based on some of the questions of the LBFQ but trying to obtain more concrete information (type of projects, societies and professional bodies, journals and magazines) on professional practices. This is open data that others can build upon.

Highest academic degree

Table 7.52 – Teachers' highest academic degree (n = 22)

Highest academic degree	Freq.	Rel. freq. (%)
PhD in educational area	1	4.5
PhD in scientific area	1	4.5
Post-Bologna Masters	1	4.5
Pre-Bologna Degree	16	72.7
Pre-Bologna Masters	3	13.6

The professional profile of teachers is mostly of a Pre-Bologna Degree level (72.7 %) with a minority with masters and PhD graduations.

Table 7.53 – Highest academic degree (n = 22)

Rel. freq. (%)	9.1	4.5	13.6	9.1	9.1	4.5	4.5	9.1	13.6	4.5	4.5	4.5	4.5	4.5
Freq.	2	1	3	2	2	1	1	2	3	1	1	1	1	1
Description of highest academic degree	Degree in Biology	Degree in Biology (Educational)	Degree in Biology and Geology Teaching	Degree in Chemical Engineering	Degree in Chemistry	Degree in Chemistry (Educational)	Degree in Metallurgical and Materials Engineering	Degree in Physics (Educational)	Degree in Physics and Chemistry Teaching	Masters in Biology and Geology Teaching	Masters in Chemistry	Masters in Earth Sciences	PhD in Chemistry	PhD in Education (Supervision)

Most teachers have degrees in educational areas (54.5 %), close to the number of those in scientific areas (45.6 %), a contrast with the data from the LBFQ (30 % from educational areas).

Experience in several roles

Table 7.54 – Years in several roles (estimates, n = 24)

	Supervisor of teacher trainees	Teacher trainer	Head of facilities	Group coordinator	Department coordinator	AP coordinator
5 or less	4	6	10	11	7	2
between 6 and 10	0	1	10	6	4	1
between 11 and 15	0	1	3	2	0	0
16 or more	1	0	0	0	0	0

	Science club' coordinator	Projects' coordinator	Education for health programme coordinator	Study room coordinator	Head of form' coordinator	Head of form
5 or less	6	6	3	2	7	2
between 6 and 10	3	0	0	0	1	11
between 11 and 15	0	0	0	0	0	5
16 or more	0	0	0	0	0	6

	DGEstE or DRE	Other institution	Member of the general council	Member of the pedagogical board	Member of the head teachers' office
5 or less	1	3	9	6	5
between 6 and 10	0	0	1	7	3
between 11 and 15	0	0	1	2	0
16 or more	0	0	0	0	0

The respondents had generally leading roles related to the subject group, such as head of facilities, group or department coordinator. At a school level, these leading roles can also be seen, as members of the pedagogical board, the general council, the head teachers' office or head of form' coordinator. Most were heads of form, with some experience in coordinating Science clubs and projects. 6 teachers reported being supervisors of teacher trainees and 8 doing teachers' professional development.

Membership in professional bodies

Table 7.55 – Membership in professional bodies (n = 24)

Membership of professional or scientific body in the last five years	**Freq.**
Portuguese Association of Biology and Geology Teachers (APPBG)	6
Research center in higher education institution	1
Portuguese Society of Chemistry (SPQ)	2
Portuguese Society of Physics (SPF)	3
Page in social network related to the subject area teaching	6
Other	3

The participation in professional bodies in the last five years is not common in the respondents, with 6 belonging to the Portuguese Association of Biology and Geology Teachers and only a minority in SPQ or SPF (n = 2 or 12.5 %, respectively). The participation in pages in social networks related to the subject area teaching is equally or more common than a participation in a professional body (25 %). This level of participation provides a great contrast with the LBFQ, reporting over 82 % of participation in these kinds of institutions (Martins et al., 2002, p. 8).

Regular use of journals and magazines

Table 7.56 – Regular use of journals and magazines (n = 24)

Regular use of journals and magazines (at least once a term)	A Física na Escola	Enseñanza de las Ciencias	Gazeta da Física	International Journal of Science Education	Investigações em Ensino de Ciências	Journal of Chemical Education	Revista Brasileira de Ensino de Física	Review of Research in Education	Revista Lusófona de Educação	Science Education	Other
Freq.	1	6	9	4	6	3	2	1	1	5	4

The "Gazeta da Física" (Physics Gazete, 37.5 %) or the journals "Investigações em Ensino de Ciências" (25.0 %), "Enseñanza de las Ciencias" (Science Teaching) (25.0 %), Science Education (20.8 %) or International Journal of Science Education (16.7 %) are the most read journals and magazines, at least once a term.

Projects and initiatives in the last five years

Table 7.57 – Projects and initiatives in the last five years (n = 24)

Projects and initiatives in the last five years	Freq.
Ciência Viva	12
Invitations to researchers for seminars to students on subject themes	13
National meeting of Science Education	2
Ilídio Pinho Foundation	3
iTEC: Designing the Future Classroom (European Schoolnet)	1
School newspaper	7
Research project linked to higher education institution	6
Eco-Escolas programme	6
NUCLIO Projects	1
SCIENTIX (European Schoolnet)	1
Segura Net	1
Science Week/Day	18
Health Week/Day	9
Other	3

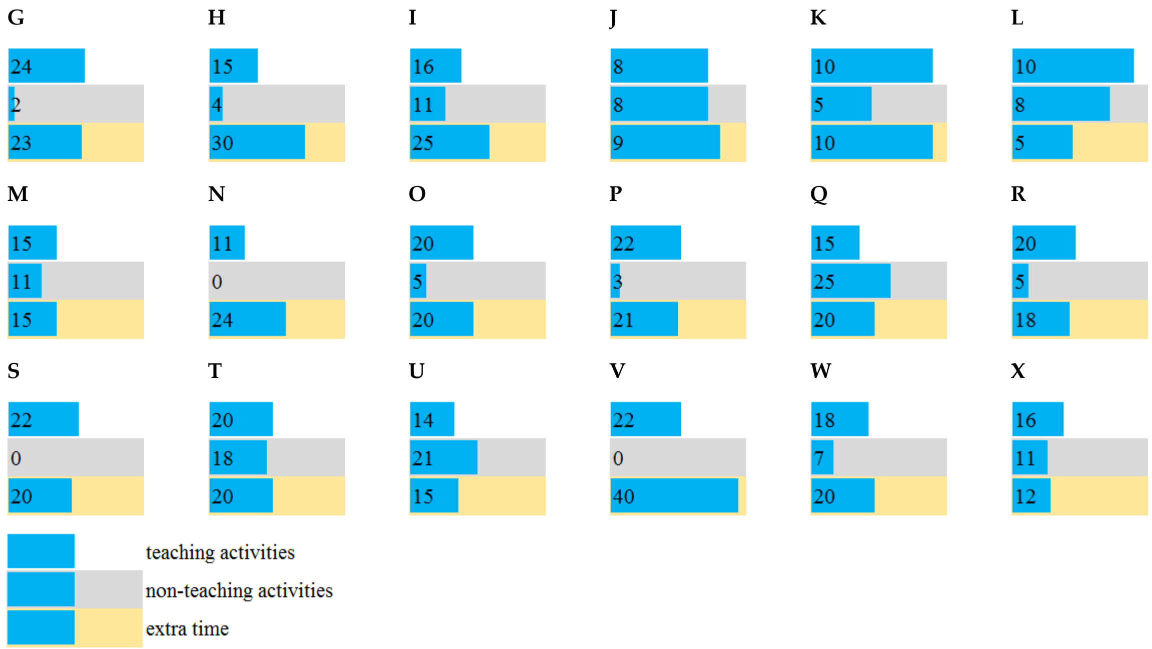
In the last five years, the most participated projects and initiatives were Science Weeks/Days (75.0 %), invitations to researchers for seminars to students on subject's themes (54.2 %), "Ciência Viva" (50.0 %), followed by the School newspaper (29.17 %), research projects linked to higher education institutions (25.0 %) or the "Eco-Escolas" (Eco Schools) programme (25.0 %).

Weekly working hours

The weekly extra time dedicated by teachers to school is in general overwhelming (average of 22.5 hours).

Table 7.58 – Weekly working hours for each respondent (n = 24)

A	B	C	D	E	F
24	20	18	20	24	22
16	0	12	6	3	6
14	22	40	28	21	28



Even in situations with reduced teaching times (N) or lack of non-teaching activities (S) the extra load is proportionally large. The average teaching time per week is 19.25 hours, with non-teaching activities filling 8.9 hours in average.

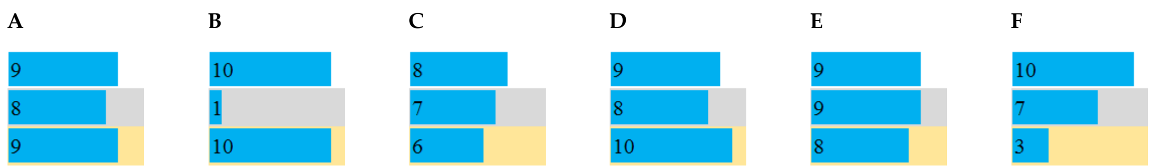
Table 7.59 – Weekly hours per activity and basic statistics (n = 24)

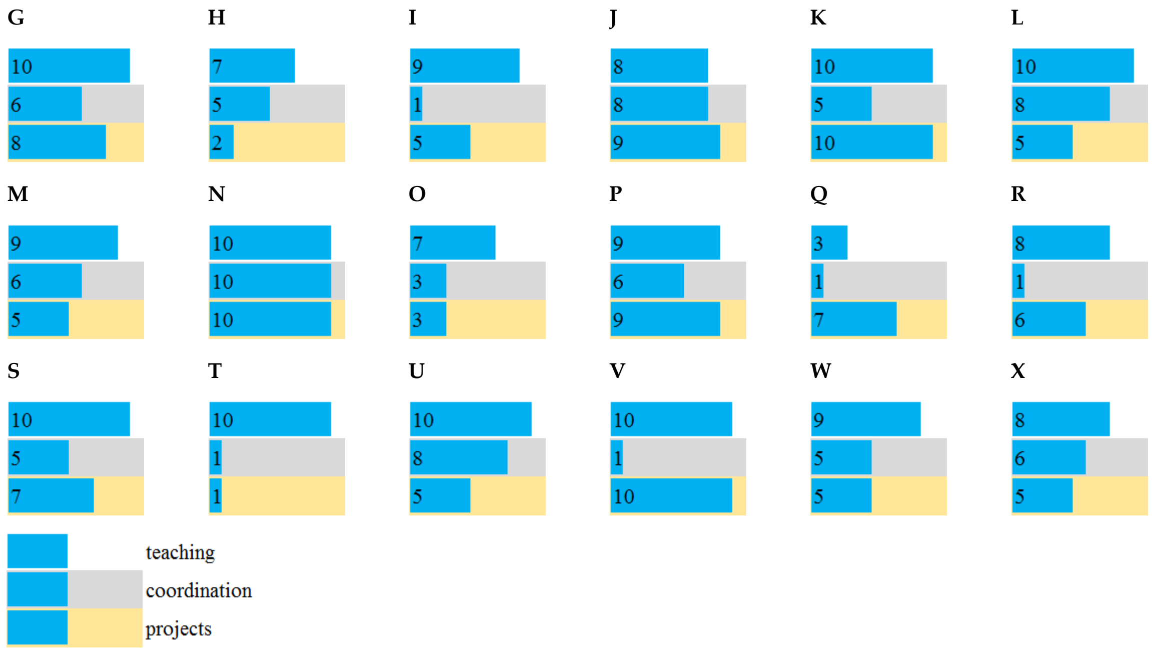
Weekly hours/Statistic	Minimum	Maximum	Mean	Standard dev.
Teaching activities	11	24	19.25	3.55
Non-teaching activities	2	25	8.93	6.57
Extra time	12	40	22.46	7.31

Motivation for diverse professional activities

The degree of motivation to fulfil teaching duties is mostly high, with 87.5 % of teachers moving the slider above position 7 in a 10 positions scale.

Table 7.60 – Degree of motivation for diverse professional activities for each respondent (n = 24)





In coordination roles, the motivation is not so consistent, with 41.7 % of teachers positioning the slider in position 5 or below. Concerning projects, 37.5 % of teachers also position the slider in position 5 or below.

Considering leaving the profession in the last year

Most respondents did not consider leaving the profession in the last year (83.3 %).

Table 7.61 – Considering leaving the profession in the last year (n = 24)

Considering leaving the profession in the last year	**Freq.**	**Rel. freq. (%)**
No answer	1	4.2
No	20	83.3
Yes	3	12.5

In the following section, an interpretation of this analysis will be made, in the attempt to answer several research questions. Some implications will also be addressed, at policy, professional development and pedagogical levels.

7.6 Coda

In this Coda I will try to answer the research questions based on the findings from the data analysis. Each research question will be presented, followed by the evidence supporting a finding.

RQ 1 What attitudes and expectations do teachers and students have towards the new model of SLS?

In broad lines, most teachers understand the new model as a laboratory dedicated to practical work, where half-shift lessons take place, and full shifts lessons take place in regular classrooms for theoretical lessons, just like the previous model for Science learning spaces in place. This main principle was not clearly understood by teachers and head teachers, and the main features that create this divide are still in place – timetables, textbooks, separate spaces, etc. It is not common for teachers to change the configuration of tables in the labs and only in two schools are all Science lessons taught in these spaces, despite the increase in number of labs.

Concerning the design elements of the SLS, the attitudes and expectations towards them will be approached in the next sub-research question.

RQ 1.1 What elements of the new model are more and less valued? Why?

One of the most valued elements, in the sense of high frequency of use and positive reasons that justify this frequency, is the teaching wall:

> M: It has enough space to represent any kind of diagram, connections, concept maps, among others;
>
> U: It allows schemas of diverse information, very effectively to diagram the entire teaching process from beginning to end of lesson;
>
> I: To share results between groups of students;
>
> S: To frequently give status reports during lessons;
>
> N: To synthesise themes;
>
> R: Sometimes some of the materials stored in the teaching wall are needed.

The extended areas for writing seem to be important, facilitating the use by teachers and groups of students during lessons to share results, give status reports, diagrams or synthesis.

However, the easy access to materials stored in the teaching wall or transparent storage modules is not harnessed in a frequent way, at least during an activity in an improvised way. As most of the labs have not assigned theoretical lessons, this use can be minimised as practical activities are mostly planned in advance. Even though almost half of the teachers' value visibility in the storage modules as facilitating improvisation, the system used in schools to organise material and equipment in these storage modules might not support this kind of use, as 3 teachers mentioned. Teacher T, for example commented in this regard:

> I needed more time to organise the laboratories and prep rooms. The operational assistant that used to act as laboratory technician has now more roles to fulfil as the school has reduced staff.

Movable benches allowing reconfiguration of the space are valued by teachers mostly in practical lessons, something that is only occasionally done by the majority (n = 16). Again, as the labs in its majority were not assigned for all Science lessons, including theoretical, minimises the application of this feature. It is expected that from diverse uses of the labs (national examinations' school team, enrolments' team, group and department meetings, students' projects and Science clubs, open days or professional development), this flexibility is put more into practice.

The transparency between labs and prep room is not frequently used by teachers, and is not implemented in 44.4 % of the identified schools. Only three teachers very frequently let their students go to the prep room, but interestingly not in schools that have full transparency. The reasons put forth by teachers by this blockade are the lack of physical transparency or students' level of autonomy:

> W: I don't use that possibility as much as I would like as some students (a significant number) are not sufficiently autonomous.

In one case, one teacher reports that this is sometimes a high-level decision:

> X: In some schools where I have taught, there is a policy of denying free access to students to the equipment available in labs.

I have also noticed that the minimum height of the transparency in the walls separating these two spaces is variable across schools, between 1.40 m or 1.70 m, minimising the lines of sight. I have also contacted with at least two schools that cover the transparency with paper, so that teachers and students can't see each other. The reasons presented by some teachers and technicians were the loss of attention of students or even that some teachers feel uncomfortable being seen by others. These are issues that will need further enquiry. The proposed height of 1.40 m to allow installation of shelves in the prep room at that height leaves me also with some concerns on the visibility that the teacher can have of students' actions in the prep room, particularly in the fixed benches with a height of 90 cm.

The transparency between labs was only present in 38.9 % of schools and the frequency of exchange of ideas between colleagues that casually had seen another one teaching was reported as occasional by 50 % of teachers. The lack of transparency was advanced by 25 % of teachers as the main reason for this not happening, but 45.8 % of teachers report that it's common for colleagues to enter the lab to search or store material, ask questions or even observe lessons, and so, in this case, transparency would not be an advantage.

The transparency, even after several years of use of the new labs, is still a dividing element, with some teachers enjoying and valuing its use and others, perhaps more than the first, not making use of it.

The use of honeycombs is valued by most teachers to store bags and jackets in the beginning of practical lessons and for them, facilitates the circulation in the lab and keeping benches uncluttered for practical work. In some cases, these were moved to another space due to limited lab areas, limiting its used, as teacher W reports:

> The honeycombs inside the lab would make circulation difficult (taking too much space of the lab). If put outside the lab, they would be in a zone without visual control with the risk of theft.

The exhibition of students' works in the lab once or at least twice a year is valued by 80.3 % of the respondents, and is interpreted as an appreciation of students' work, making space more welcoming and participated.

The help point, the washing modules or the fume cupboards were not included in this survey as the implementation was inconsistent in the many visited schools, and the use of these elements didn't have a proper pedagogical rationale that required scaffolding in this study.

RQ 1.2 How do teachers compare the new model with the previous laboratories/regular classrooms for Science classes?

The comparison between old and new is mostly positive in almost every questioned aspect. More broadly, prep rooms, labs, classrooms, school libraries, specialised spaces such as auditorium, canteen, bar, teachers' room, storage areas, Science teachers working spaces, living spaces are all positively classified, in descending order. Concerning the Science spaces, location in school and ventilation and air temperature were considered the most troublesome by a significant number of teachers, followed by spaces' areas and relationships between spaces. Technology, acoustics, safety conditions, aesthetics, lighting, typology of spaces, number of labs, specific equipment and furniture all gather positive reviews when compared with the previous spaces. There is a minority of teachers that still aspires to the classical configuration of labs with fixed benches with electrical and water infrastructure in the centre.

RQ 2 What teaching and learning activities are taking place in the new SLS?

Establishing causal relationships between changes in physical aspects of learning spaces, and changes in teaching practices would be naturally naive. The rebuilding project by PE was not part of an integrated approach to school Science reform, intervening on policy, organisational, curriculum, assessment, professional development and other domains usually included in educational change models. With the concurrent dismissal of close to 30% of the professional body of teachers, in a scale and method without precedent, it would also be imprudent to try that kind of study in a demobilised profession.

Beyond improvements in physical comfort or eventual motivation that these changes can bring, pedagogical choices, or organisational and managerial choices that support a certain pedagogy are not achieved in this way.

In theoretical lessons, from the data gathered in the survey, tasks supporting coordination between scale domains of activity and multiple modalities are not consensual practice among respondents in the three situations presented. 45.8 %, 54.2 % and 41.7 % of the teachers, respectively to situations A1, A2 and A3, positioned themselves in positions 8, 9 and 10 of the scale, stating that the activity was very much aligned with their teaching practice.

In practical lessons, tasks supporting coordination between scale domains of activity and multiple modalities are, for a larger number of teachers, more aligned with their teaching practice, except in situation B3. 62.5 %, 70.8 % and 37.5 % of teachers positioned themselves in positions 8, 9 and 10 of the scale, respectively to situations B1, B2 and B3, stating that the activity was very much aligned with their teaching practice.

In project/open enquiry lessons, tasks supporting coordination between students' scales of activity are not usually aligned with their teaching practice. 20.8 %, 33.3 % and 29.2 % of the teachers positioned themselves in positions 8, 9 and 10 of the scale, respectively to situations C1, C2 and C3, stating that the activity was very much aligned with their teaching practice.

Project/open inquiry lessons, without proper time in the curricula, are usually developed in the practical component of the scientific subject (n = 15) and club or extra-curricular activity (n = 8). It is predictable that the time devoted to this kind of projects is marginal due to time limitations.

RQ 2.1 To what extent, if any, does the new model facilitate or inhibit these activities?

Teachers reported that visibility to daily use' materials and equipment facilitates its integration during a lesson (56.5 %), a feature that could support tangible and ponderable activities during theoretical lessons. 37.5 % of teachers' report that whenever possible, they try to have non-practical lessons in the labs, as they favour the use of materials and equipment in those lessons.

The uses given to the teaching wall to make diagrams, synthesising information or support students' collaboration in general support mostly practical lessons but are general enough to be helpful across activities. As there is no formal moment for open inquiry activities in the curriculum anymore and theoretical lessons are mostly occasional or rare in the labs, there is not enough data from this survey to clarify these affordances. Some affordances were identified in case studies.

The honeycombs facilitate circulation and uncluttered benches across types of activities.

The configuration of movable benches mostly used is one of standard rows, in both practical and theoretical lessons. Some affordances were identified in the case studies.

RQ 2.2 How do these activities contrast with previous data from the Portuguese LBFQ?

Instead of questioning teachers on the use of specific methods as in the LBFQ (problem solving, direct instruction, group work, etc.), to then make comparisons with methods used in the SLS, the concern was to understand the level of coordination of scale domains in theoretical, practical and open enquiry activities and the emphasis given to interoceptive, exteroceptive and proprioceptive modalities.

The LBFQ questioned teachers about the frequency of use of certain teaching strategies in classrooms, with the most frequent being exercise and problem-solving, reception learning, reception learning with questions and demonstrations and correcting tests and homework. Practical work was not common (Martins et al., 2002, p. 107) as was not group work (p. 111) and the use of the textbook and the chalkboard was common, for both preparation of lesson plans and during the lessons. The study affirms then that there was evidence of the dominance of theoretical teaching (p. 123).

The framing of the questions in the survey related to teaching and learning activities paints a different picture however, as it tried to separate the three modes of science lessons (at a secondary level), theoretical, practical and project/open inquiry and provided concrete situations, however transferable to individual practices, for teachers to respond to. In this sense, it is not so much concerned with the use of a certain method (report writing, discussion of results) but on how multiple scale domains and modalities are coordinated in certain activities, something that is not inherent to the method itself.

RQ 2.3 What are teachers perceived needs regarding the organisation, management and use of the new SLS in these activities?

A minority of schools has in place a set of support tools in the organisation and management of labs and prep rooms, such as specialised operational assistant, a proper plan, a digital inventory, a yearly budget, or systems for chemical storage, labelling and waste management. Two teachers mentioned the lack of training, time and support from a lab technician:

> A: Training in lab management and inventory;
>
> T: I needed more time to organise the laboratories and prep rooms. The operational assistant that used to act as laboratory technician has now more roles to fulfil as the school reduced staff.

In the LBFQ these are also the two main problems reported, that make practical work difficult (Martins et al., 2002, p. 140), besides the lack of spaces and equipment.

Needs were also observed in case studies 4 and 5 and in the following chapter, these will be addressed in detail, in the development of the model of organisation and management of the SLS.

RQ 3 What are the differences between the idealised and applied SLS model in the intervened schools?

From the 7 elements presented to teachers (teaching wall, transparent storage modules, movable benches, honeycombs, shelves), transparency between spaces (prep room and adjacent labs) is the least implemented in schools.

The number of labs increased, but the allocation of these spaces for all Science lessons was not done by the head teacher. Was this the result of an old habit, the number of students limiting the use of labs for all Science lessons, a lack of communication of the assumptions of the new model of SLS or a disagreement with the model? From several conversations with head teachers and teachers across the country, I am inclined to say that it is the result of an old habit, combined with issues on the communication of the assumptions of the new model. There are also cases where the labs are attributed to non-scientific subjects, undermining the full allocation of labs to Science lessons and making use of expensive resources in limited ways.

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8. Contributions, limitations, and implications of this work

In this chapter, I synthesise my interpretation of the contributions, limitations and implications of this work.

8.1 Contributions

The contributions of this work, read from my own position as a researcher, are the following:

1. A snapshot of the evolution of models of school Science spaces across school construction plans in Portugal from the early "Liceus" in the beginning of the XXth century to Parque Escolar's project in the early XXIst century;
2. The development of the Studio concept for secondary Science Education, gathering influences from the Design Studio in architectural education, the Reggio Emilia Atelier in preschool education and the Physics Studio in undergraduate education, emphasising its main features on curriculum, pedagogy, assessment, professional development and community links;
3. A theoretical contribution to question and reframe some concepts in Activity Theory, particularly SSAT, and its implications for secondary Science Education, particularly for curriculum and professional development;
4. The SLS activity analysis methodology, the concept of pedagogical graphic novel and the instruments to create this kind of documentation of practice, as an instrument to facilitate students' and teachers' meta-conceptual thinking and reflective practice;
5. The Digital Research Notebook as an instrument to support Science Education researchers and qualitative researchers more broadly in their daily activities;

6. The empirical work from 5 case studies and one survey, and the tentative answers to the research questions of this study, possibly contributing to the planning, construction and review of secondary schools' Science spaces' rebuilding projects in Portugal and abroad;
7. A model of organisation and management of the SLS, including the concept of Digital Lab Notebook, a professional development course and a website, that can support teachers, students, lab technicians, heads of facilities and teacher trainers in the daily activities in the SLS and in school Science laboratories more broadly. These contributions are described in the following section.

8.2 Some practical contributions to schools' daily activities in the SLS

The co-design of a model for organising and managing the new SLS had as main reference the CLEAPPS project (http://www.cleapss.org.uk/) in the UK and case studies 4 and 5, besides work in two other schools not mentioned in the case studies, in the Oporto and Lisbon regions. The laboratory technician Marilia in the school in the Algarve region was key in the development of the model providing several of the elements of the model from her practice.

After the contextual task analysis in case studies 4 and 5, several instruments were developed to support organisation and management of the SLS:

1. Templates in Microsoft Powerpoint to create plans of the Science spaces;
2. Templates in Microsoft Powerpoint to create diagrams of storage modules of the Science spaces;
3. Templates in Microsoft Excel to create timetables of the Science spaces;
4. Templates in Microsoft Powerpoint to define functional areas in the Science spaces;
5. Templates in Microsoft Word for registering information such as useful contacts, characterisation of functional areas, acquisition requests, broken material and damaged equipment, borrowed material and equipment, infrastructure and furniture problems, checklists related to safety and maintenance (quick, weekly, term, annual, safety, adopted materials, ongoing activities);
6. Templates in Microsoft Excel for inventories, stocks and waste, with filters and adapted to printing;

7. A database of 420 substances and mixtures common in schools in Microsoft Excel, containing information on the EC number and name, signal word, pictograms, storage code and link to the Wikipedia article;
8. A database of companies that provide waste elimination services;
9. A collection of 330 safety data sheets of substances and mixtures common in schools in digital format;
10. A label generator for substances and mixtures using a macro in Microsoft Excel;
11. Label templates for waste, containers, spill kits, functional areas, folders and storage modules;
12. A collection of ISO 7010:2014 symbols for printing;
13. Posters related to the use of space according to the type of activity.

A standard workflow for activity preparation and follow-up was also developed using a storyboard format, to communicate the model to other teachers and technicians.

The instruments developed, together with information and documents collected from different sources (e.g., CLEAPPS, ECHA, Ministry of Education, ISO, Sigma Aldrich) were organised into a Digital Lab Notebook and in the website Laboratórios Escolares (http://laboratoriosescolares.net).

Some of these instruments were developed with Cecília Silva and Cristina Azeredo, teachers from two schools, in the Oporto and Lisbon Region (namely the templates for labels, the substances and mixtures database, the collection of safety data sheets) and support of an IT expert, Nuno Pacheco (the label generator for substances and containers).

The instruments and workflows were applied and further refined in two professional development courses affecting 39 teachers in 14 schools in the Lisbon and Setubal regions in 2016.

8.2.1 Developing a Digital Lab Notebook

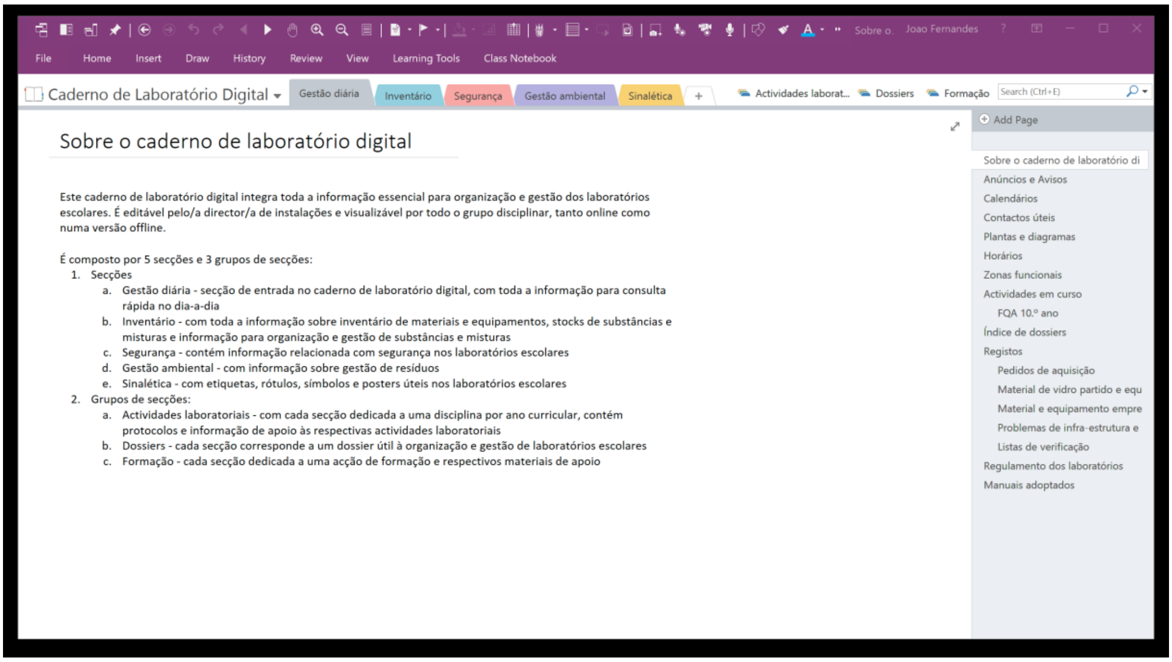

Figure 8.1 – Frontpage of the Digital Lab Notebook

The Digital Lab Notebook (DLN) developed in this work integrates all the essential information to organise and manage the Science Learning Studios. It is editable by the head of facilities, and viewable (or editable, if the head of facilities chooses so) by any teacher, both online, via a browser, and offline, with syncing abilities provided by the application Microsoft OneNote, in multiple devices and operating systems. The offline mode is important in schools with Internet access problems.

The organisation of the digital notebook resembles that of a paper notebook, with labelled sections, pages and subpages, that can contain text, images, video, online resources, links, tags, any type of files, embedded documents, and so on. It is also searchable, and the model provided can be easily adapted to the school needs, with pages, sections, section groups and the entire content fully editable.

The main structure of the model notebook has 5 sections and three section groups. The 5 sections are:

1. Daily management – main section, with all the required information by teachers for everyday use. It can have several pages such as announcements, calendars, useful contacts, lab plans and diagrams, timetables, identification of functional areas, ongoing practical activities, inventory of folders, records (acquisitions, broken glassware, lent material, checklists), regulations, adopted textbooks;

2. Inventory and Stocks – inventory of materials and equipment, stocks of substances, mixtures and waste, storage categories and codes, pictograms, database of substances and mixtures, labels, incompatible substances, material safety data sheets, Hazard and Precautionary statements;
3. Safety – general rules for students, list of first aid kit contents and antidotes, common accidents and first aid measures, first aid manuals, safety manuals, emergency plan, emergency building documents, posters about toxic substances, effects in the organism and precautionary measures, organic substances with ignition temperature below 35 °C, table of resistance of glove types to several substances, and use of active safety equipment;
4. Environmental management - treatment to several substances, sheets for treatment operations on several types of waste, limit emission values in the water sink of several substances, poster about waste, treatment and end destination;
5. Signage – several templates for labels, ISO 7010:2014 signs, posters.

Besides these sections, the Digital Lab Notebook has also 3 section groups organised into 1) Practical activities, in which each section inside can contain protocols and supporting materials for the activities usually carried out by teachers per academic year and subject; 2) Folders, with multiple sections for the digital version of paper files containing relevant information for the organisation and management of the SLS, such as equipment manuals, catalogues, Science fairs activities' protocols, management documents; 3) Professional development, to collect the materials and notes of professional development programmes in which teachers participate and which are relevant for the group.

The DLN is available for free download from the website "Laboratórios Escolares".

8.2.2 Developing a professional development course

During the project, I developed and participated as trainer in a professional development course certified by the "Conselho Científico-Pedagógico de Formação Contínua" (Continuing Training Scientific-Pedagogical Council, CCPFC), responsible for the accreditation of teacher training courses in Portugal, with the reference DC-4357/15, and entitled "Organização e Gestão de Laboratórios Escolares" (Organisation and Management of School Laboratories), through the Teacher Training Center Calvet de Magalhães, in Lisbon. The Training Center Ordem de Santiago in Setubal has also offered this course. In total, 39 teachers in 14 schools have applied and adapted the model developed in this work to their school needs. Not all the schools had Parque Escolar's intervened buildings (only

5 out of 14), but the model proved flexible and abstract enough to be transferred to the basic and secondary schools involved.

The 25 hours' courses offered one credit in a blended learning "curso de formação" (training course) format and took place in April-May 2016. The course was organised in 7 sessions with the following activities:

1. The opening session (2h30m), face-to-face, to get to know and understand teachers and schools' needs, to present the concept of SLS implemented by Parque Escolar and its rationale, to present an advance organiser of the course and define some early tasks to be done before the next session, namely creating a Microsoft account for the heads of facilities to later manage the DLN, install software required during the course, test a Skype call with the trainer and gather preliminary information to prepare the next sessions (Science spaces timetables, building plans and inventory);
2. Session 2 (4h), online, to prepare the essential documents to implement the organisation and management model, such as a general plan of the Science spaces, a diagram of the storage modules, the timetables of the labs and a digital inventory. Video tutorials and templates were made available for guidance, besides the online meetings using Skype, a VoIP application, with group conversations and email support;
3. Session 3 (4h), face-to-face, in each school, to review the documents prepared in the previous session, observe the spaces and define functional areas in the several spaces, using a digital diagram;
4. Session 4 (4h), online, to prepare a document defining in detail the functional areas, rearrange spaces, furniture and resources, print and display labels, forms and documents in the several functional areas and photograph the prototype areas for later review;
5. Session 5 (4h), online, to plan the organisation and management of substances and mixtures according to the CLEAPPS' storage categories and codes, prepare a digital inventory of substances and mixtures from a template, organise material safety data sheets into a digital and paper folder, print labels for substances and mixtures containers using a label generator, define the waste management policy and label the available waste using templates and contact a company certified for waste elimination to request an estimate;
6. Session 6 (4h), face-to-face, in each school, to review the instruments and prototypes of organisation and management, complete the tasks of the previous sessions, prepare the Digital Lab Notebook with all the information gathered, prepare routine checklists, and prepare a storyboard illustrating the workflow before and after the lab activity using all the instruments and areas prepared during the course;

7. Session 7 (2h30m), face-to-face, in one of the schools, to view an example in practice, to share the application and adaptation of the proposed model to each school, reflect on the model and evaluate the course.

The course and all its resources are available on the website "Laboratórios Escolares".

8.2.3 Developing the website "Laboratórios Escolares"

As an outreach to schools and the wider community of the results of the research project and the development work done in this thesis, a website was launched to support the users of the Science Learning Studio in their activities. The site, designed and programmed by Tiago Santos, with illustrations by Beu Beu Studio, is available in http://laboratoriosescolares.net and has the following structure:

1. About: introduces the concept of Science Learning Studio, its rationale, main aspects, previous models of school Science spaces, its implementation by Parque Escolar;
2. Safety: makes available resources related to safety in the school Science laboratories such as a database of substances and mixtures, H and P statements, a label generator for substances and mixtures containers, information about waste management, safety manuals, pictograms, first-aid manuals;
3. Organisation: makes available resources to support the organisation and management of schools' laboratories such as the digital lab notebook, a database of national and international suppliers, a database of equipment, label templates, posters, signs, checklists, inventory and stock list templates;
4. Teaching and training: makes available resources that support teaching and learning, including applications, Science Learning Studio's pedagogical information, graphic novels produced in the project, educational resources related to the scientific subjects, publications about experimental Science teaching, micro-scale chemistry, a open courseware on the organisation and management of labs and prep rooms etc.;
5. Research: makes available references and publications, a digital research notebook in open access, making transparent the research process to the site visitors, a digital museum and information about the research project;

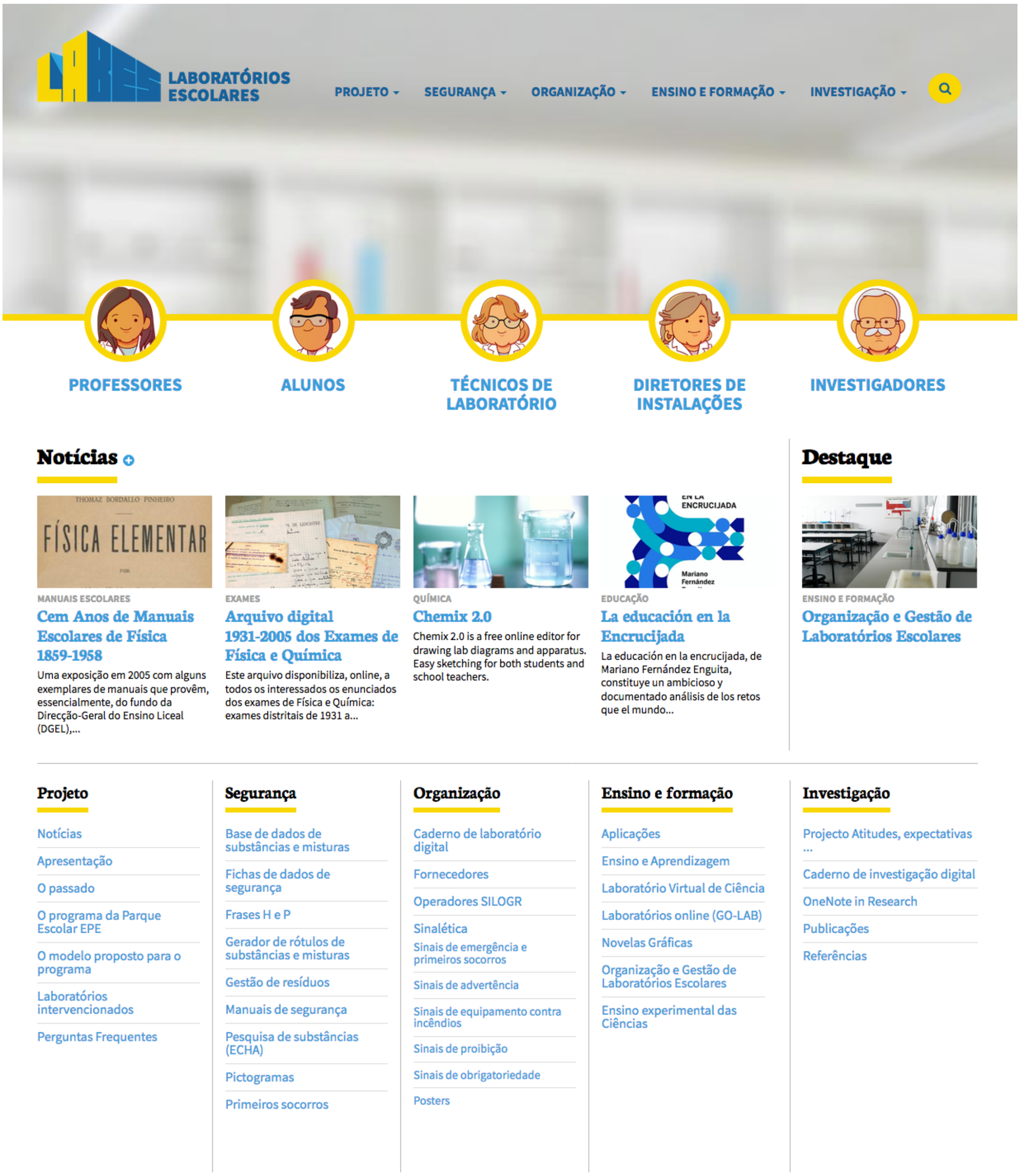

Figure 8.2 – Frontpage of the website http://laboratorioescolares.net

8.3 Limitations

As a work spanning several years, with several advances and setbacks, with alternating part-time and full-time involvement, huge quantities of data and innovations in practice and writing happening mostly in the later stages of research, this thesis has several inconsistencies that I would have tried to reduce if I could go back in time.

First, I would have done further historical research on the evolution of school Science spaces models in Portugal, searching for guidance on primary sources from the work of Alegre (2009) and Nóvoa and colleagues (2003).

Second, I would have designed the initial empirical work, following a quick review of the literature, to observe practice in Design Studios, Reggio Emilia Ateliers and Physics Studios, probably with an ethnographic approach, followed by observation of AP, theoretical and practical lessons in year 12 of a single group in a single class, taught by a Science teacher. The use of Pedagogical Graphic Novels at this stage would be helpful, together with the use of the Digital Research Notebook to manage several aspects of research.

Third, I would have approached Activity Theory earlier to develop the SLS activity analysis methodology, at the same time doing case studies in the year 10 or 11 Science subjects Biology and Geology and Physics and Chemistry, illustrated by Pedagogical Graphic Novels, and develop its use as a tool and a process for analysis of practice, from the point of view of both teachers and students. Development work at this stage would have been to design a professional development course on the use of this instrument and to develop the analysis methodology with teachers in this course.

Fourth, concerning the survey, I would have extended the sample of the survey with support from Parque Escolar and eventually Scientific and Professional bodies, gathering more representative data and emphasising questions more related to SLS learning activities, using examples from the case studies or illustrated Pedagogical Graphic Novels.

Fifth, concerning the organisation and management of SLS, I would begin the empirical work early in the research project, so that it could inform and support the development work done and more schools, at an earlier stage, could make use of the instruments and training, particularly those in the rebuilding process.

8.4 Implications

Can the essential features of the Design Studio, the Reggio Emilia Atelier and the Physics Studio be crystallised into a Secondary Science Learning Studio? Can a negotiated curriculum and a structured curriculum achieve a balance, particularly in final secondary exam years and pressures on results in standardised tests as the main goal of this school level? Can the pedagogy in the Studio integrate authentic tasks, project-based learning, everyday situations, open inquiry, apprenticeship, with short meaningful reception learning and structured activities, interspersed with peer-tutoring, cooperative learning, tangibles and ponderables, modelling and simulation, combining multiple expressive languages that not only the verbal? Are co-teaching and teaching assistants possible in a professional culture not used to it? Can assessment be enriched with short quizzes, 360° group assessment, standardised tests and documented work by the student and the teacher? Can teachers become researchers and reflective practitioners in a collegial way? Changing secondary Science in Portugal is multidimensional and hard.

School construction plans can provide the pivot for multiple changes departing from spaces and technology but also including curriculum, pedagogy, assessment, professional development, culture and initial teacher training. Educational planning could view these construction projects, that take place every 20 years or so, as the focal point for discussing, planning and implementing major innovations across multiple education system domains.

During the construction of new schools, and looking at the data gathered in the survey, review procedures should be in place that support architects, technical teams and suppliers in applying a model of spaces to their projects and continuously generate iterations across project phases. Communication strategies should also be in place so that architects, technical teams, head teachers, and teachers understand the rationale beyond the new spaces models and exemplary designs are put in evidence, as much as common mistakes.

The participation of teachers and students in the design phase of the intervention to co-design a model of spaces, plan its implementation and assess its use is, I believe, crucial not just from a budgetary perspective, but also to put in practice a culture of democratic participation in major social projects in Portugal.

Concerning the professional development of Science teachers, and particularly concerning curriculum development, I believe that programmes should emphasise not experimental teaching, but curriculum development in multiple Science lesson modes, theoretical, practical and open inquiry/project, which engage students' multiple modalities and support iterative programs linking sensory-perceptual, conceptual and meta-conceptual domains. The concepts of tangibles, ponderables and project/open enquiry as icons of learning activities that can achieve this coordination can be a departing point for these development programmes. Besides this curriculum development programme, another one focused on documentation of practice, either with Pedagogical Graphic Novels or other methods, is, I believe, essential to support reflective practice of both students and teachers and could become a daily use tool in SLS and classrooms as much as the art journal is for artists and architects or the panel is for Reggio Emilia teachers. The multiple uses of this kind of tool and process can provide concrete opportunities for improving teaching, learning, community links, and make visible the artistry of teaching, fighting deskilling and calling the best and the most creative in the society for the teaching profession.

Finally, the use of Digital Research Notebooks can become an instrument to document research practice and provide opportunities for reflective practice. It can also become a facilitator to implement collaborative, participatory research projects, that reveal the rigorous, ethical, careful, educated, falsifiable subjectivity that can drive scientific research.

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Appendices

Appendix 1: Questionnaire

Atitudes, Expectativas e Práticas nos Novos Laboratórios Escolares do Ensino Secundário

Introdução

Caro/a colega,

Antes de mais, obrigado pela sua disponibilidade.

Desenhámos este inquérito por questionário com o objectivo de produzir materiais de apoio para a utilização dos novos laboratórios escolares, bem como perceber as suas expectativas e práticas nestes novos espaços. Para isso, colocámos as seguintes questões de investigação:

1. Que atitudes e expectativas têm os professores em relação aos novos laboratórios escolares?
2. Que actividades estão a ter lugar nestes espaços?
3. Que necessidades de organização, gestão e utilização dos laboratórios escolares são identificadas pelos professores?

Gostávamos que esta fosse uma oportunidade para expressar a sua experiência no uso dos novos laboratórios escolares.

Tentámos usar uma abordagem visual, com ilustrações e fotos de situações reais em sala de aula, que lhe poderá também ajudar a reflectir sobre as suas práticas.

Com a análise das suas respostas, vamos desenvolver materiais de apoio (p.e. rótulos de substâncias, sinalética, manuais de equipamentos em formato digital, sistema de organização de espaços, reagentes e material, blocos de notas de laboratório, novelas gráficas pedagógicas em vários temas curriculares) a colocar no novo site http://laboratoriosescolares.net, que será lançado até ao final de 2015. Estes materiais de apoio serão dedicados à organização e gestão de laboratórios escolares e incluirão guiões visuais de actividades nos novos espaços.

Dividimos este questionário em 5 secções:

1. Informações básicas sobre si
2. Utilização dos novos laboratórios escolares
3. Actividades de ensino e aprendizagem nos novos laboratórios escolares
4. Intervenção da Parque Escolar
5. Informações detalhadas sobre si

Pode preencher este questionário por partes, retomando a sua resposta sempre que quiser. Para isso, clique no link na BARRA DE TOPO preta de qualquer uma das páginas SEGUINTES que diz "**Guardar respostas e continuar mais tarde**". Terá apenas de fornecer o seu e-mail, no qual receberá um link único que deve seguir para continuar a responder.

Prevemos que o tempo de resposta oscile entre os 30 minutos e 1 hora.

Disponibilizaremos os dados das respostas, de forma anónima, num repositório de acesso aberto, de forma a ficar acessível a toda a comunidade escolar e de investigação. Os resultados da análise serão também disponibilizados no site **Laboratórios Escolares.**

Obrigado!

A equipa do projecto **Atitudes, expectativas e práticas nos novos laboratórios escolares do ensino secundário (PTDC/MHC-CED/5116/2012)**, financiado pela Fundação para a Ciência e Tecnologia.

Vitor Duarte Teodoro - Investigador Responsável (vdt@fct.unl.pt)
João Fernandes - Investigador (jpsf@fct.unl.pt)

1. Informação essencial sobre si

1. Qual é a Escola onde está colocado/a actualmente?
(Seleccione a sua escola a partir dos respectivos distritos e concelhos)

2. Em que ano lectivo iniciou ou vai iniciar a utilização dos NOVOS LABORATÓRIOS ESCOLARES?

- 2008/2009
- 2009/2010
- 2010/2011
- 2011/2012
- 2012/2013
- 2013/2014
- 2014/2015
- No próximo ano lectivo

3. Durante quantos anos leccionou NA ESCOLA EM QUE SE ENCONTRA, antes da intervenção da Parque Escolar?

4. Qual é o seu Grupo de Recrutamento?
(Escolha uma das seguintes respostas)

- ☐ Física e Química (510)
- ☐ Biologia e Geologia (520)
- ☐ Outro:

5. Quais são os anos de escolaridade e as disciplinas que leccionou nos NOVOS LABORATÓRIOS ESCOLARES?
(Seleccione todas as opções que se apliquem)

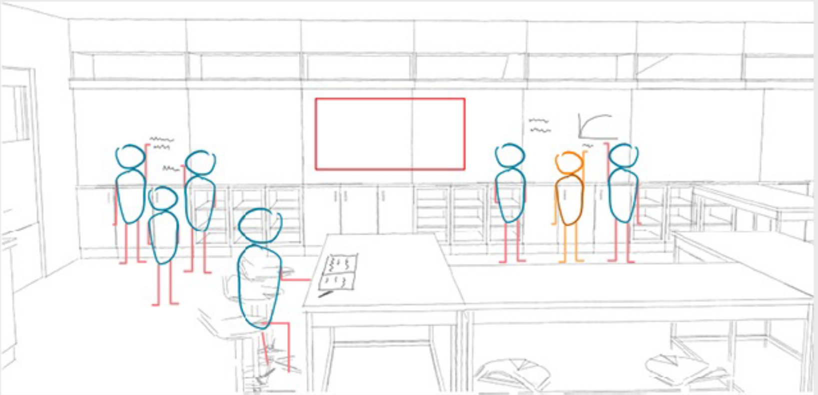
- ☐ Ciências Naturais do 3.º Ciclo
- ☐ Biologia e Geologia 10.º ano
- ☐ Biologia e Geologia 11.º ano
- ☐ Biologia 12.º ano
- ☐ Geologia 12.º ano
- ☐ Ciências Físico-químicas do 3.º Ciclo
- ☐ Física e Química 10.º ano
- ☐ Física e Química 11.º ano
- ☐ Física 12.º ano
- ☐ Química 12.º ano
- ☐ Área de Projecto 12.º ano
- ☐ Qualquer ano/disciplina de Cursos Tecnológicos/Profissionais
- ☐ Outros:

6. Qual é a sua idade?

2. Utilização dos novos Laboratórios Escolares

Nesta secção, apresentamos-lhe 7 ilustrações de situações que exemplificam usos possíveis dos novos laboratórios escolares.
Gostaríamos de perceber de que forma as situações apresentadas fazem sentido para si, se são aplicáveis e se expressam adequadamente as suas práticas.

A. Colaboração com alunos na parede de ensino



A parede de ensino ocupa grande parte de uma parede do laboratório, disponibilizando uma área alargada de colaboração para grupos de alunos e professor. Esta parede permite projecção, escrita e afixação, bem como arrumação de materiais e equipamentos.

7. Esta característica ("parede de ensino") está presente nos novos laboratórios?

- Sim
- Não
- Parcialmente
- Não tenho a certeza

8. Com que frequência utiliza a parede de ensino como área de colaboração com alunos?

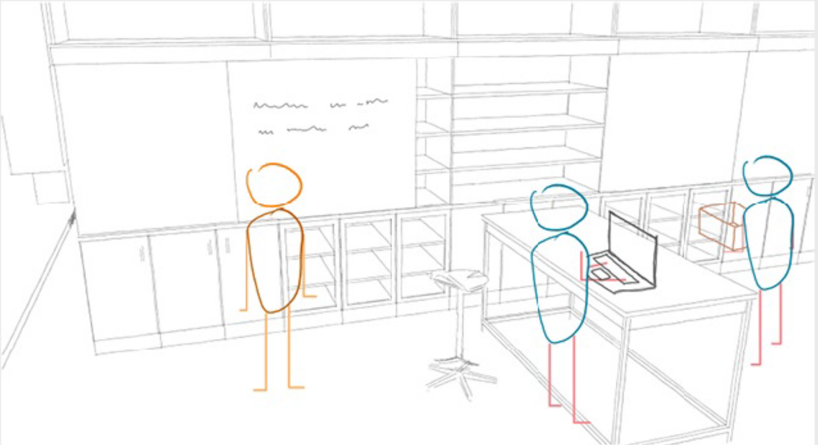
- Com muita frequência (em todas ou quase todas as actividades de grupo)
- Com alguma frequência
- Raramente (tipicamente uma ou duas vezes por período)
- Nunca

9. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- Tento partilhar a frente de sala com os alunos
- A qualidade do quadro não é adequada para este tipo de actividade
- Não existe parede de ensino
- Não é uma actividade típica do meu estilo de ensino
- Os alunos trabalham em grupo apenas nas bancadas
- Outra:

10. Se quiser, pode comentar aqui a situação com mais detalhe.

B. Utilização "improvisada", no decorrer de uma actividade, de equipamentos e outros materiais acessíveis na parede de ensino e nos módulos de arrumação



O acesso prático a materiais e equipamento na parede de ensino pode facilitar demonstrações rápidas, pequenas experiências e observações.

A transparência nos módulos de arrumação sob a zona de escrita e projecção e sob as bancadas laterais facilita a identificação rápida dos materiais e equipamento, úteis para improvisar uma actividade durante uma aula.

11. Esta característica ("transparência nos módulos de arrumação") está presente nos novos laboratórios?

- Sim
- Não
- Parcialmente
- Não tenho a certeza

12. Com que frequência utiliza de forma improvisada, no decorrer de uma actividade, equipamentos ou materiais acessíveis na parede de ensino e nos módulos de arrumação?

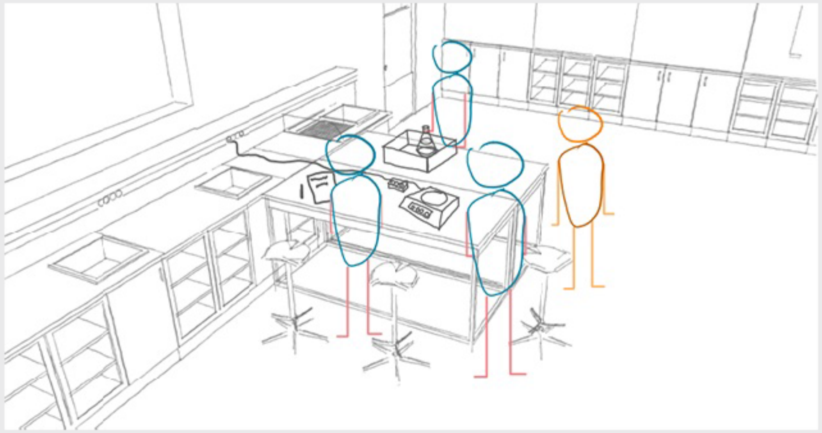
- Com muita frequência (pelo menos duas vezes por mês)
- Com alguma frequência
- Raramente (tipicamente uma ou duas vezes por período)
- Nunca

13. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- A visibilidade para materiais e equipamentos de uso quotidiano facilita a improvisação de actividades
- Na parede de ensino e nos módulos de arrumação transparentes mais próximos não estão arrumados equipamentos e materiais adequados a este tipo de utilização
- Não é habitual improvisar actividades que não planeei
- Não existe transparência na maioria dos módulos de arrumação
- Outra:

14. Se quiser, pode comentar aqui a situação com mais detalhe.

C. Rearranjo de bancadas móveis consoante o tipo de actividade



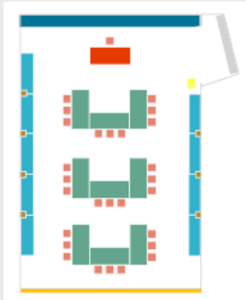
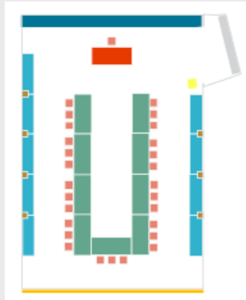
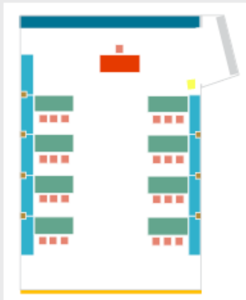
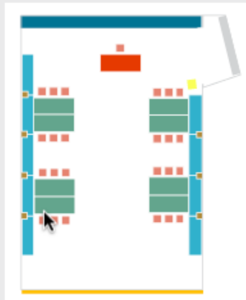
As bancadas móveis permitem o rearranjo do espaço de acordo com o tipo de actividades a desenvolver na aula.

Estas bancadas, da mesma altura das bancadas fixas, permitem também o alargamento da área de trabalho junto dos pontos de corrente e de água nas laterais.

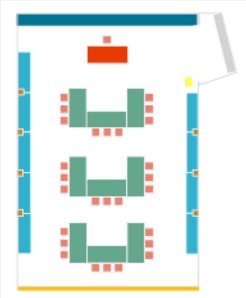
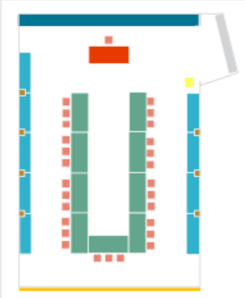
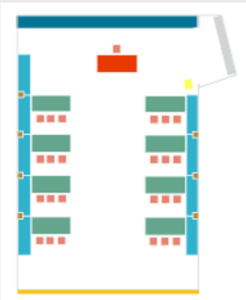
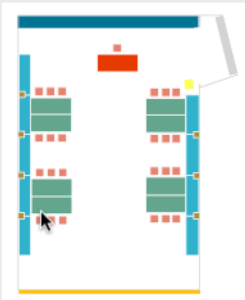
15. Esta característica ("bancadas móveis") está presente nos novos laboratórios?

- Sim
- Não
- Parcialmente
- Não tenho a certeza

16. Das seguintes configurações de bancadas móveis, qual é a que usa com maior frequência para aulas práticas/laboratoriais?

- 
- 
- 
- 
- Outra:

17. Das seguintes configurações de bancadas móveis, qual é a que usa com maior frequência para aulas de exposição de matéria/resolução de exercícios?

- 
- 
- 
- 
- Outra: ____

18. Com que frequência rearranja as bancadas móveis de acordo com o tipo de actividades?

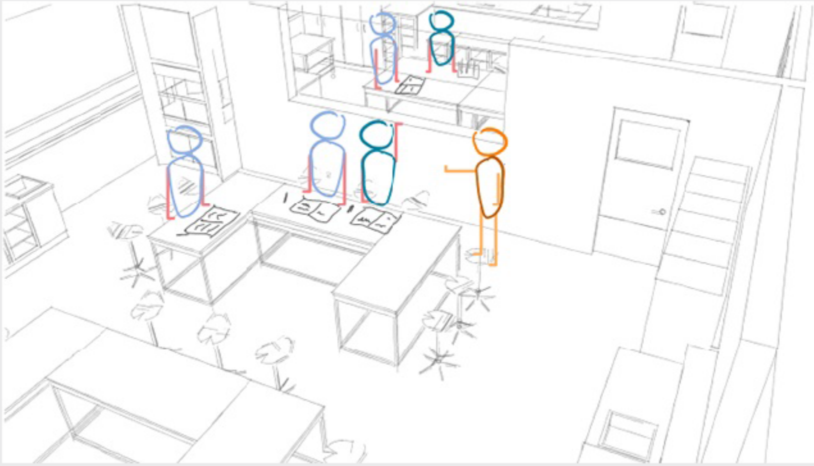
- Com muita frequência (em todas ou quase todas as aulas)
- Com alguma frequência (apenas em aulas práticas/laboratoriais)
- Raramente (tipicamente uma ou duas vezes por período)
- Nunca

19. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- Tento, sempre que possível, adaptar o espaço ao tipo de actividades
- Prefiro bancadas fixas ao centro, como num laboratório tradicional, porque os alunos estão sempre virados para a frente de sala
- As bancadas são muito pesadas para permitir um rearranjo fácil
- Os alunos não participam no rearranjo do espaço
- Antes da aula seguinte é necessário repor a configuração inicial
- A área de laboratório não permite grande diversidade de reconfigurações
- As bancadas móveis não são suficientemente estáveis para trabalhar com segurança
- Não existem bancadas móveis
- Outra: ____

20. Se quiser, pode comentar aqui a situação com mais detalhe.

D. Alunos em trabalho autónomo na SALA DE APOIO no decorrer de uma actividade no laboratório



O professor acompanha a actividade dos alunos no laboratório, podendo ao mesmo tempo observar alunos em trabalho autónomo através da transparência para a sala de apoio.

O professor também pode estar na sala de apoio e manter contacto visual com a turma.

21. Esta característica ("transparência para a sala de apoio") está presente nos novos laboratórios?

- Sim
- Não
- Parcialmente
- Não tenho a certeza

22. Com que frequência os alunos se deslocam autonomamente à sala de apoio no decorrer de uma actividade no laboratório?

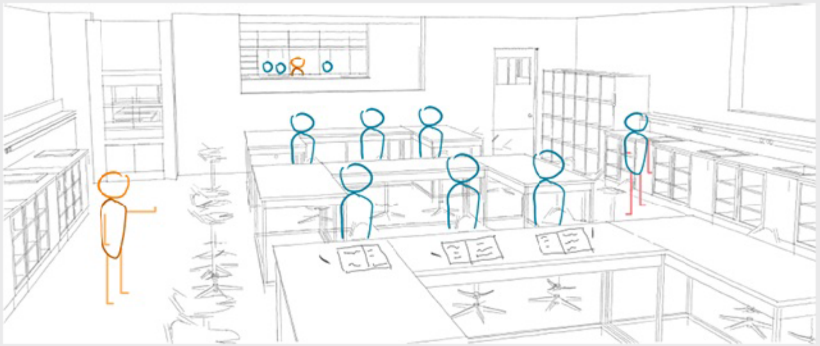
- Com muita frequência (em todas ou quase todas as actividades laboratoriais)
- Com alguma frequência
- Raramente (tipicamente uma ou duas vezes por período)
- Nunca

23. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- Não existe vidro para a sala de apoio
- A transparência para a sala de apoio foi tapada com material opaco para garantir alguma privacidade
- A transparência para a sala de apoio foi tapada com material opaco para evitar distracções de alunos
- Nem todos os meus alunos são suficientemente autónomos para o fazer
- Sempre que possível tento que os meus alunos tenham autonomia no decorrer de actividades
- Existem armários na sala de apoio que tapam a visibilidade porque não existe outro lugar onde os colocar
- Outra:

24. Se quiser, pode comentar aqui a situação com mais detalhe.

E. Observação "casual" de actividades na aula de um/a colega no laboratório adjacente



A transparência entre laboratórios e nas portas permite a observação no dia-a-dia das actividades desenvolvidas por colegas, criando oportunidades de partilha.

25. Esta característica ("transparência entre laboratórios") está presente nos novos laboratórios?

- Sim
- Não
- Parcialmente
- Não tenho a certeza

26. Com que frequência troca impressões com colegas sobre uma actividade que observou casualmente nas suas aulas?

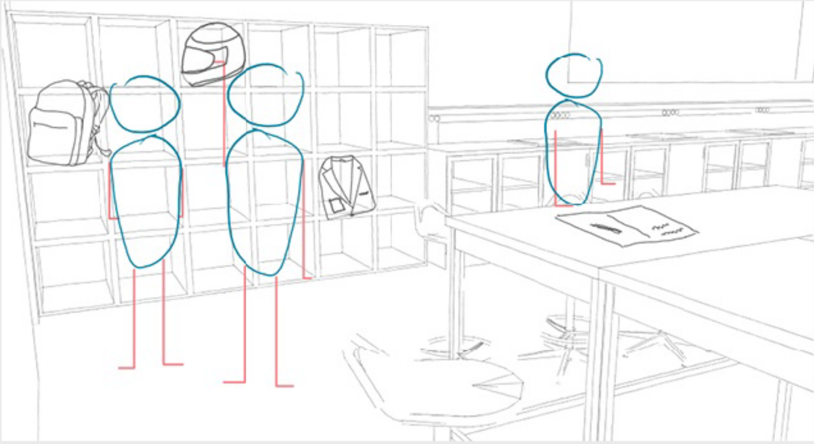
- Com muita frequência (todas as semanas)
- Com alguma frequência
- Raramente (tipicamente uma ou duas vezes por período)
- Nunca

27. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- É uma oportunidade de observar a actividade dos colegas sem o peso da avaliação
- Não existe vidro para o laboratório adjacente ou não há visibilidade directa por questões estruturais
- A transparência para o laboratório adjacente está tapada com mobiliário ou outro tipo de material opaco
- Não me sinto confortável em observar os meus colegas ou conversar com eles sobre as actividades desenvolvidas
- Não me sinto confortável em ser observado durante as aulas e por isso evito fazer o mesmo
- É habitual colegas circularem nas aulas para recolher ou entregar material, fazer perguntas ou mesmo assistir
- Outra:

28. Se quiser, pode comentar aqui a situação com mais detalhe.

F. Utilização dos favos para arrumação de mochilas e casacos no início de todas as aulas



Os favos de arrumação libertam a área central e as bancadas do laboratório, facilitando a movimentação de alunos e evitando acidentes.

29. Esta característica ("favos de arrumação") está presente nos novos laboratórios?

- Sim
- Não
- Parcialmente
- Não tenho a certeza

30. Com que frequência utiliza os favos para arrumação de mochilas e casacos no início de todas as aulas?

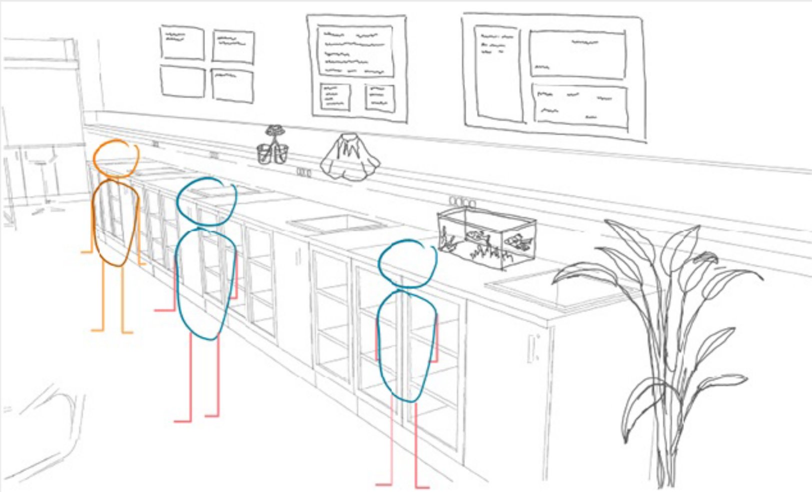
- Com muita frequência (em todas ou quase todas as aulas)
- Com alguma frequência (apenas em aulas práticas/laboratoriais)
- Raramente (tipicamente uma ou duas vezes por período)
- Nunca

31. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- A utilização dos favos facilita a circulação no laboratório e uma menor desarrumação das bancadas
- Os favos estão preenchidos com outro tipo de materiais (p.e. dossiers)
- Não existem favos de arrumação
- Os favos estão numa zona sem controlo visual pelo que colocam riscos de roubo
- Não sinto necessidade de utilizar os favos
- Outra:

32. Se quiser, pode comentar aqui a situação com mais detalhe.

G. Exibição de trabalhos de alunos no laboratório



As prateleiras, para além de servirem como superfície extra para colocação de materiais e equipamentos, permitem a decoração dos laboratórios com trabalhos de alunos, equipamentos ou posters.

33. Esta característica ("prateleiras") está presente nos novos laboratórios?

- Sim
- Não
- Parcialmente
- Não tenho a certeza

34. Com que frequência expõe trabalhos de alunos no laboratório?

- Com muita frequência (pelo menos duas vezes por ano)
- Com alguma frequência (uma vez por ano)
- Raramente
- Nunca

35. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- Considero importante haver trabalhos expostos, uma vez que valorizam o trabalho dos alunos e tornam o espaço mais acolhedor e participado
- Como os laboratórios são usados por vários professores e alunos, não consigo coordenar essa tarefa
- As prateleiras estão ocupadas com outros materiais
- As prateleiras não são adequadas à exposição de trabalhos
- Os trabalhos expostos costumam ser vandalizados
- Não existem prateleiras
- Não me costumo preocupar com a exposição de trabalhos de alunos
- Outra:

36. Se quiser, pode comentar aqui a situação com mais detalhe.

3. Actividades de ensino e aprendizagem nos novos laboratórios escolares

Nesta secção, apresentamos-lhe 9 situações de sala de aula, suportadas com fotografias, de actividades de ensino e aprendizagem. Estas 9 situações estão agrupadas em 3 tipos de aula:

A - aula de exposição de matéria/resolução de exercícios
B - aula prática/laboratorial
C - aula de projecto/inquérito aberto

Gostaríamos de perceber em que medida cada uma destas situações está de acordo com a sua prática de ensino.

As situações descritas têm um contexto disciplinar que pode não ser o seu, mas podem sugerir actividades semelhantes na sua área curricular.

Por favor tenha em conta que se NÃO mexer nos *sliders* para representar a sua opinião sobre as situações apresentadas, consideraremos que NÃO respondeu à questão.

A1. Actividade em aula de exposição de matéria/resolução de exercícios

(P. e.: Os alunos, em pequenos grupos, são convidados a beber copos com água de vários tamanhos. A professora então pergunta-lhes "Quantas moléculas de água acabaram de beber?", apoiando depois os grupos nos cálculos necessários)

Os alunos, em pequenos grupos, colaboram na resolução de problemas qualitativos ou quantitativos. Estes problemas podem abordar aspectos conceptuais, numéricos ou computacionais, e **partem de uma situação imaginada ou do quotidiano dos alunos que é de alguma forma motivadora**.

37. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino

Esta situação está em grande parte de acordo com a minha prática de ensino

A2. Actividade em aula de exposição de matéria/resolução de exercícios

(P. e.: Aluna demonstra a um colega a situação descrita numa ficha de trabalho sobre plano inclinado, recorrendo ao seu caderno diário como rampa e a um carro tipo lego. Cada um dos alunos propõe respostas à ficha de trabalho, que depois discutem em grupo, tentando chegar a um consenso. Esse consenso é depois comunicado à turma e o professor dá feedback)

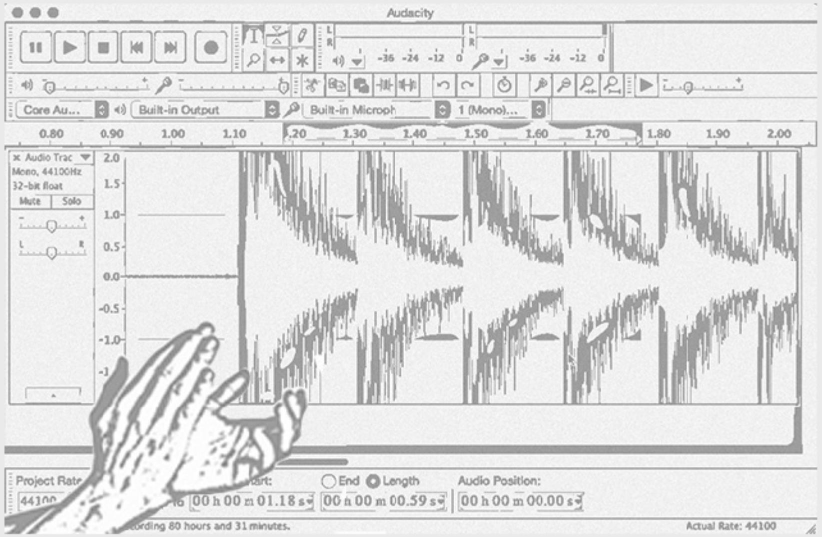
Em pequenos grupos, a partir de uma situação proposta pelo professor, os alunos instruem-se mutuamente, discutindo em grupo até chegar a uma resposta consensual. As respostas são depois comunicadas a toda a turma e o professor dá feedback.

38. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino

Esta situação está em grande parte de acordo com a minha prática de ensino

A3. Actividade em aula de exposição de matéria/resolução de exercícios



(P. e.: Professor pergunta a aluna quantas palmas consegue bater num segundo. Aluna tenta bater palmas o mais rapidamente possível, enquanto o professor grava num programa de gravação no computador a tentativa. Os dados capturados são depois analisados em grande grupo, introduzindo-se o hertz e o conceito de proporcionalidade inversa)

Os alunos são convidados a exemplificar com o corpo conceitos abstractos, p.e. velocidade, aceleração, ângulo, etc.

39. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino	Esta situação está em grande parte de acordo com a minha prática de ensino

B1. Actividade em aula prática/laboratorial

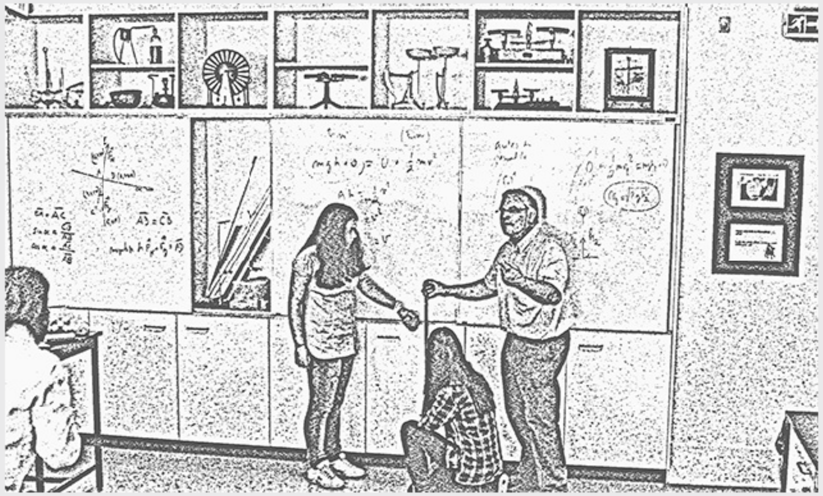
(P. e.: Para registo da actividade, os alunos fotografam o procedimento da actividade laboratorial, usando mais tarde as fotos tanto no relatório como na apresentação de resultados ao restante turno)

Os alunos registam as actividades práticas/laboratoriais com fotografia ou vídeo, dando o seu cunho pessoal ao trabalho final, que pode ser tanto um relatório padrão ilustrado como um pequeno vídeo ou uma sequência de slides.

40. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino		Esta situação está em grande parte de acordo com a minha prática de ensino

B2. Actividade em aula prática/laboratorial



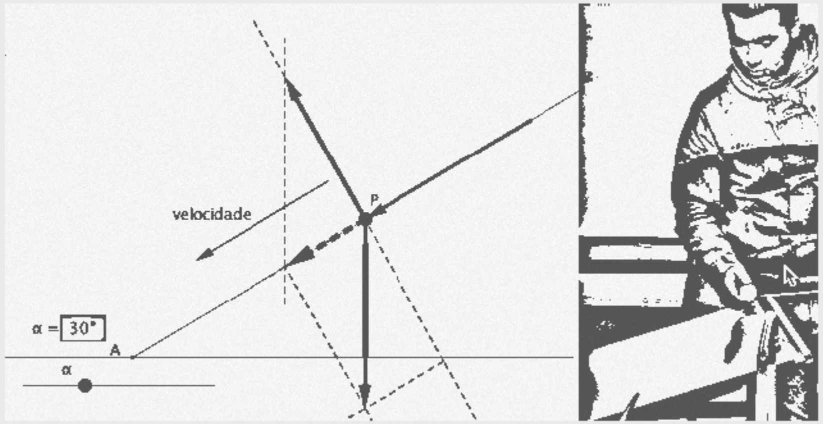
(P. e.: Alunas participam em demonstração interactiva do professor para o grande grupo, na queda livre de uma bola de ténis, medindo a distância com uma fita métrica e com um cronómetro de telemóvel)

Os alunos observam/participam em **demonstrações interactivas do professor, recorrendo a equipamento de laboratório ou objectos do quotidiano**. Em pequenos grupos, discutem e fazem previsões dos resultados dessas demonstrações.

41. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino		Esta situação está em grande parte de acordo com a minha prática de ensino

B3. Actividade em aula prática/laboratorial



(P. e.: A partir de um modelo de plano inclinado simulado com uma bola de golfe, uma mesa e um ponteiro extensível, um aluno representa esse modelo num software de geometria)

A partir da manipulação de objectos ou do uso do seu próprio corpo, os alunos representam esquematicamente o modelo conceptual, com software, materiais ou papel e lápis.

42. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino		Esta situação está em grande parte de acordo com a minha prática de ensino

C1. Actividade em aula de projecto/inquérito aberto

(P. e.: Alunas decidem estudar o impacte ambiental de uma indústria importante na proximidade da escola, um tema para o qual estão sensíveis e que as afecta colectivamente. A professora apoia o grupo no desenho de investigação para o estudo da qualidade do efluente industrial, a partir das águas residuais lançadas numa ribeira local.)

Os alunos iniciam investigações autênticas a partir dos seus interesses e com significado para si, para a escola e para a comunidade. Não sabem à partida como vai decorrer a actividade e aprendem o que é necessário para conseguir o seu objectivo, trabalhando colaborativamente com o professor e com peritos e elementos da comunidade.

43. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino		Esta situação está em grande parte de acordo com a minha prática de ensino

C2. Actividade em aula de projecto/inquérito aberto

UMA AVENTURA - UM PROJECTO

Projecto, segundo definição da UNESCO (Glossary of Educational Technology Terms), é uma actividade prática significante, de valor educativo, que visa um ou vários objectivos. Implica pesquisas, resolução de problemas e, muitas vezes, uma produção. Tal actividade é planificada e conduzida pelos alunos e pelo professor, em conjunto, num contexto real e verdadeiro.

Desta forma, as alunas Ana Isabel Antão, Laura Gonçalves e Mariana Rodrigues, do 12.º B, têm, nas aulas de Área de Projecto, orientadas pela professora Paula Castelhano, como principal objectivo de investigação analisar a genotoxicidade de efluentes tratados de indústrias de cartelarias do concelho de Alcobaça. Neste projecto, têm como colaboradores directos as empresas, as quais cedem os seus efluentes já tratados, pois possuem recursos humanos e materiais adequados para efectuar o tratamento físico e químico de efluentes, com certificados de qualidade ambiental.

A Genotoxicidade é a capacidade que alguns compostos, xenobióticos, têm de induzir alterações no material genético de organismos, sendo essas alterações responsáveis pelo aparecimento de cancros e doenças hereditárias. O conhecimento do potencial genotóxico de um fármaco ou de substâncias presentes no meio ambiente é uma informação essencial para os departamentos de ambiente, regionais ou nacionais, no que se refere ao estabelecimento de riscos para o homem e para o ambiente.

Assim, um projecto implica, por parte dos intervenientes, motivação e coerência no caminho a percorrer, pelo que deve estar de acordo com os valores e princípios que regem a escola. Numa explicação sucinta das vantagens do Trabalho de Projecto, pode dizer-se que é bom para envolver os alunos e levá-los a pensar – o que é, obviamente, uma finalidade essencial da escola. O mais importante é que estas alunas aprendam e ganhem gosto por aprender, pois um projecto é criado para resolver um problema, para estudar um tema ou para realizar um sonho.

Alexandra Francisco, Bárbara Quitério e Inês Severo, 10ºA

LABORATÓRIOS ABERTOS

No passado dia doze de Maio, os alunos do 10ºC, 10ºD, 12ºA, 12ºB e 12ºC dinamizaram os Laboratórios Abertos de Biologia e Geologia e de Física e Química, integrados na Semana Cultural, e com a supervisão dos professores Ana Fernandes, Isabel Carreira, Inês Madaleno, Luísa Fonseca, Paula Arralão e Sérgio Teixeira.

Nesse dia, os alunos transformaram-se em cientistas, realizando experiências que foram mostradas a outros alunos da ECB e a crianças do Agrupamento de Escolas da Benedita, do Centro Social Paroquial e do CEERIA.

Os alunos divertiram-se, ensinando, e todos esperam que para o ano estas actividades se repitam.

Patrícia Ribeiro, 10ºD

16 CIÊNCIA, TECNOLOGIA E AMBIENTE

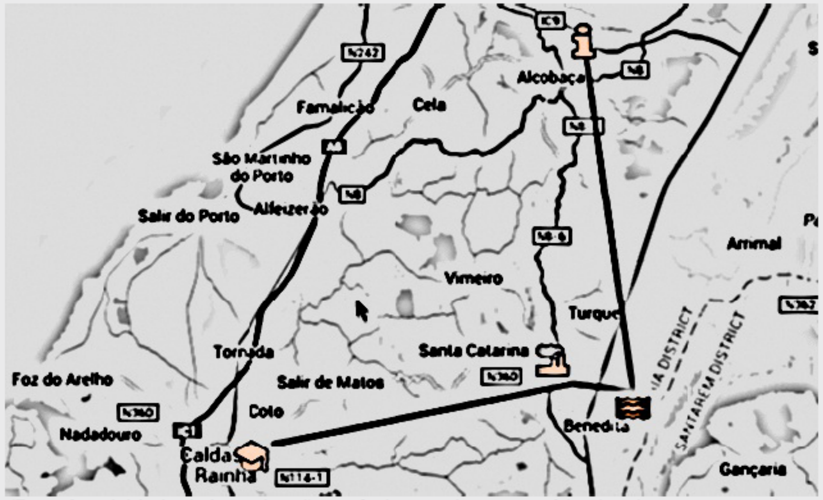
(P. e.: O resultado da investigação levada a cabo pelas alunas é publicado no jornal local, chamando a atenção da comunidade para o tratamento inadequado dos efluentes da indústria em causa)

Os produtos da investigação autêntica de alunos são comunicados à comunidade, podendo levar a mudanças socialmente significativas.

44. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino		Esta situação está em grande parte de acordo com a minha prática de ensino

C3. Actividade em aula de projecto/inquérito aberto



(P. e.: A actividade de investigação autêntica tem lugar em vários locais, num centro de investigação de uma faculdade, na indústria local, numa ribeira ou na câmara municipal)

A actividade de investigação autêntica tem lugar em vários locais, envolvendo diversidade de interacções com objectos, pessoas e instituições.

45. (Arraste o botão para representar a sua opinião)

Esta situação não está de todo de acordo com a minha prática de ensino		Esta situação está em grande parte de acordo com a minha prática de ensino

46. Com que frequência utiliza os novos laboratórios escolares para aulas essencialmente de exposição de matéria/resolução de exercícios?

- ○ Com muita frequência (em todas ou quase todas as aulas desse tipo)
- ○ Com alguma frequência
- ○ Raramente (tipicamente uma ou duas vezes por período)
- ○ Nunca

47. Qual é A PRINCIPAL RAZÃO que melhor justifica a sua resposta à questão anterior?

- Sempre que posso uso os laboratórios para aulas que NÃO SEJAM de actividade laboratorial/prática, uma vez que privilegio o uso de materiais e equipamento também neste tipo de aula
- A taxa de ocupação dos laboratórios não permite requisitá-los para este tipo de aulas
- Não sinto necessidade dos laboratórios para este tipo de aulas
- A direcção não autoriza o uso dos laboratórios para este tipo de aulas
- Os laboratórios foram atribuídos para todas as aulas de Ciências
- Os laboratórios não têm condições para uma turma inteira
- Outra:

48. Em que contextos desenvolve ou desenvolveu projectos ou actividades de inquérito aberto? (Seleccione todos os que se apliquem)

- Componente prática/laboratorial da minha disciplina científica
- Clube ou actividade extra-curricular
- Área de Projecto no 12.º
- Área de Projecto no 3.º ciclo
- Cursos Tecnológicos ou Profissionais
- Outro:

49. Durante quantos anos leccionou a disciplina de Área de Projecto de 12.º ano?

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4

50. Como classifica a sua experiência na leccionação desta disciplina? (Arraste o botão para representar a sua opinião)

Foi uma experiênci a pouco estimulant e — Foi uma experiênci a muito estimulant e

51. Quais são AS PRINCIPAIS RAZÕES que melhor justificam a sua resposta à questão anterior? (Seleccione todas as que se apliquem)

- Não foi uma disciplina que escolhi leccionar e por isso não foi tão motivadora
- A diversidade de actividades desenvolvidas foi pouco estimulante, tipicamente relatórios e trabalhos escritos apenas
- As características da disciplina permitiram desenvolver actividades motivadoras, tanto para para mim como para os meus alunos
- As características da disciplina permitiram desenvolver actividades que revelam aos alunos tanto aspectos técnico-científicos como da natureza da Ciência
- As características da disciplina permitiram desenvolver actividades para além dos espaços e tempos escolares
- As características da disciplina permitiram desenvolver actividades em colaboração com pessoas e entidades dentro e fora da escola
- As turmas que leccionei não eram de áreas científicas
- Não tive os recursos suficientes para desenvolver o trabalho que pretendia nesta disciplina
- Não considero esta disciplina relevante no currículo
- Os alunos não estão preparados para as exigências de autonomia desta disciplina
- Outra:

4. A sua experiência na intervenção da Parque Escolar

Nesta secção, um pouco mais demorada no preenchimento, gostávamos de perceber de que forma experienciou a intervenção da Parque Escolar na escola em que estava colocado/a durante esse processo.

Por favor tenha em conta que se NÃO mexer nos *sliders* para representar a sua opinião sobre as situações apresentadas, consideraremos que NÃO respondeu à questão.

52. Qual foi o seu tipo de envolvimento na intervenção da Parque Escolar?
(Seleccione todos os que se apliquem)

- ☐ Pertencia a uma equipa da escola que elaborou uma proposta para os novos espaços para as Ciências
- ☐ Acompanhei ou pertencia à Direcção durante o processo
- ☐ Participei regularmente em reuniões com a Parque Escolar
- ☐ Não tive qualquer tipo de participação
- ☐ Outro: __________

53. Como compara as condições gerais de trabalho nos seguintes espaços <u>ANTES E DEPOIS</u> da intervenção da Parque Escolar?
(Arraste o botão para representar a sua opinião)

	Piorou bastante	Melhoı
Salas de aula		
Laboratórios		
Salas de preparação/apoio		
Arrumos		
Espaços de trabalho para professores de Ciências		
Sala de professores		
Espaços especializados (auditórios, refeitórios, bar)		
Espaços de convívio		
Biblioteca escolar		

54. Como compara os seguintes aspectos dos espaços para as Ciências <u>ANTES E DEPOIS</u> da intervenção da Parque Escolar?
(Arraste o botão para representar a sua opinião)

	Piorou bastante	Melhoı
Tipologia		

de espaços (laboratórios, salas de apoio, antecâmaras, arrumos, espaços para professores de Ciências, etc.)

Dimensão dos espaços (m^2)

Número de laboratórios

Localização na escola

Relação entre os vários espaços

Condições de segurança

Equipamento tecnológico (computadores, projectores, internet sem fios, quadros interactivos, etc.)

Novos equipamentos de apoio à especialidade (hotte, armários de reagentes, trolleys, etc.)

Mobiliário

Estética

Iluminação

Acústica

Ventilação, aquecimento e arrefecimento

55. De quantos laboratórios dispunham todas as Ciências (Biologia e Geologia, Física e Química, Cursos Tecnológicos) ANTES da intervenção da Parque Escolar? (não inclua salas que não estivessem no projecto da escola como laboratórios, p.e. salas improvisadas)

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56. E APÓS a intervenção?

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57. Quais foram as opções tomadas pela escola na especialização dos novos laboratórios escolares? (Seleccione todas as que se apliquem)

- ☐ Um par de laboratórios com sala de apoio por especialidade (p.e. um par para Química, outro para Biologia)
- ☐ Um par de laboratórios por área disciplinar, com sala de apoio partilhada (p.e. um para Química, o outro para Física)
- ☐ Todos ou quase todos os laboratórios são considerados polivalentes para todas as disciplinas científicas do Ensino Básico
- ☐ Todos ou quase todos os laboratórios são considerados polivalentes para todas as disciplinas científicas do Ensino Secundário
- ☐ Um laboratório ou par de laboratórios com sala de apoio para disciplinas científicas do Ensino Básico
- ☐ Os laboratórios também são usados para áreas curriculares não científicas
- ☐ Outra:

58. Quais são os usos dados aos novos laboratórios escolares na sua escola, para além da componente lectiva?
(Seleccione todos os que se apliquem)

- ☐ Secretariado de exames
- ☐ Reuniões de grupo
- ☐ Reuniões de departamento
- ☐ Apoio a eventos abertos como p.e. Semana/Dia das Ciências ou Saúde
- ☐ Reuniões com encarregados de educação
- ☐ Apoio ao desenvolvimento de projectos de alunos
- ☐ Apoio a clubes de Ciências ou semelhante
- ☐ Formação de professores
- ☐ Outro:

59. Dispõe de algum(ns) dos seguintes apoios na organização e gestão dos laboratórios escolares?
(Seleccione todas as que se apliquem)

- ☐ Assistente operacional de apoio básico aos laboratórios
- ☐ Assistente operacional, com formação e experiência, de apoio aos laboratórios
- ☐ Inventário digital
- ☐ Orçamento anual
- ☐ Plano de organização e gestão dos laboratórios, com um fluxo de trabalho bem definido
- ☐ Sistema de organização de reagentes
- ☐ Sistema de rotulagem de reagentes
- ☐ Sistema de gestão de resíduos
- ☐ Outro:

5. Informações detalhadas sobre si

Nesta última secção, pedimos-lhe informação mais completa sobre si. Considerámos relevante fazer este tipo de questões para, por um lado, caracterizar melhor os inquiridos para este estudo e, por outro, para recolher dados que permitam actualizar alguma da informação do Livro Branco da Física e da Química de 2003 sobre o corpo docente e as suas práticas, estendendo-o aos colegas de Biologia e Geologia. Agradecemos-lhe desde já a paciência.

Por favor tenha em conta que se NÃO mexer nos *sliders* para representar a sua opinião sobre as situações apresentadas, consideraremos que NÃO respondeu à questão.

60. Qual é o seu género?

- Feminino
- Masculino
- Sem resposta

61. Quais são as suas habilitações académicas mais elevadas?

- Bacharelato
- Licenciatura pré-Bolonha
- Licenciatura pós-Bolonha
- Pós-Graduação
- Mestrado pré-Bolonha
- Mestrado pós-Bolonha
- Doutoramento em área Científica
- Doutoramento em área Educacional
- Pós-Doutoramento
- Outra:

62. Qual é a designação, incluindo especialidade, da sua habilitação académica mais elevada? (p.e. Licenciatura em …, Mestrado em..., Doutoramento em...):

63. Qual é a sua situação profissional?

- Professor de Quadro de Agrupamento/Escola (PQA/PQE)
- Professor de Quadro de Zona Pedagógica (PQZP)
- Professor Contratado

64. Por quantos anos desempenhou ou desempenha as seguintes funções? (ESTIME o n.º de anos)

Docência com componente lectiva		Coordenação de Sala de Estudo	
Orientação de estágios		Coordenação de Directores de turma	
Formação de professores		Direcção de Turma	
Direcção de Instalações		Destacamento para DGEstE ou antiga DRE	
Coordenação de Grupo		Direcção de Centro de Formação	
Coordenação de Departamento		Destacamento para outras instituições	
Coordenação de Área de Projecto		Educação Especial	
Coordenação de Clube		Membro de Conselho Geral	
Coordenação de Biblioteca Escolar		Membro de Conselho Pedagógico	
Coordenação de Projectos Escolares		Membro de Direção	
Coordenação de Projecto de Educação para a Saúde			

65. Quais são as associações profissionais e científicas ou outras entidades de que foi membro nos últimos 5 anos? (Seleccione todas as que se apliquem)

- [ ] American Educational Research Association (AERA)
- [ ] Associação Portuguesa de Professores de Biologia e Geologia (APPBG)
- [ ] Association for Science Education (ASE)
- [ ] Centro de investigação em Instituição do Ensino Superior
- [ ] European Science Education Research Association (ESERA)
- [ ] European Education Research Association (EERA)
- [ ] Sociedade Portuguesa de Química (SPQ)
- [ ] Sociedade Portuguesa de Física (SPF)
- [ ] Sociedade Geológica de Portugal (SGP)
- [ ] Página em rede social de colegas da área disciplinar
- [ ] Outra(s):

66. Da lista de revistas seguinte, assinale as que consulta regularmente (aproximadamente, pelo menos uma vez por período)
(Seleccione todas as que se apliquem)

- [ ] A Física na Escola
- [ ] Educação, Formação e Tecnologias
- [ ] Enseñanza de las Ciencias
- [ ] Gazeta da Física
- [ ] International Journal of Science Education
- [ ] Investigações em Ensino de Ciências
- [ ] Journal of Chemical Education
- [ ] Revista Brasileira de Ensino de Física
- [ ] Review of Research in Education
- [ ] Revista Portuguesa de Educação
- [ ] Revista Portuguesa de Química
- [ ] Revista Lusófona de Educação
- [ ] Science Education
- [ ] Sisyphus
- [ ] Outra(s):

67. A sua escola assina alguma(s) das revistas que referiu na resposta anterior?

- Sim
- Não, mas já assinou
- Não, mas nunca assinou

68. Da lista de projectos e iniciativas seguinte, em quais participou nos últimos 5 anos? (Seleccione todos os que se apliquem)

- Ciência Viva
- Conferência Challenges
- Convite a investigadores para palestras a alunos sobre temas de especialidade
- ETwinning
- Encontro Nacional de Educação em Ciências
- Fundação Ilídio Pinho
- inGenius (European Schoolnet)
- iTEC: Designing the Future Classroom (European Schoolnet)
- Jornais Escolares
- Projecto de Investigação ligado a Instituição de Ensino Superior
- Programa Eco-Escolas
- Projectos NUCLIO
- SCIENTIX (European Schoolnet)
- Segura Net
- Semana/Dia da Ciência
- Semana/Dia da Saúde
- Outro(s): ____

69. Como qualifica a sua motivação nos seguintes aspectos? (Arraste o botão para representar a sua opinião)

Pouco motivado — Mu

- Exercício da componente lectiva
- Exercício de cargos de coordenação
- Realização de projectos

70. No último ano considerou deixar a profissão?

- Sim
- Não
- Sem resposta

71. Qual é a sua carga horária semanal (em horas)?

Componente lectiva ____

Componente não lectiva ____

72. Para além da sua carga horária semanal oficial, quantas mais horas estima trabalhar em média por semana em actividades relacionadas com a sua profissão?

Se quiser receber as suas respostas por email, insira aqui o seu endereço.

[contact("email")]

73. Esta é a última questão. Tem alguma coisa a comentar ou sugerir à equipa de investigação sobre este questionário?

Chegou ao fim deste questionário!

Obrigado pela sua paciência e colaboração.
Os resultados deste questionário, bem como os materiais de apoio desenvolvidos a partir da sua análise, serão publicados no site Laboratórios Escolares até ao final de 2015.
Desejamos-lhe um excelente fim de ano lectivo!
Até lá,

A equipa do projecto **Atitudes, expectativas e práticas nos novos laboratórios escolares do ensino secundário (PTDC/MHC-CED/5116/2012)**, financiado pela Fundação para a Ciência e Tecnologia.

Vitor Duarte Teodoro - Investigador Responsável (vdt@fct.unl.pt)
João Fernandes - Investigador (jpsf@fct.unl.pt)