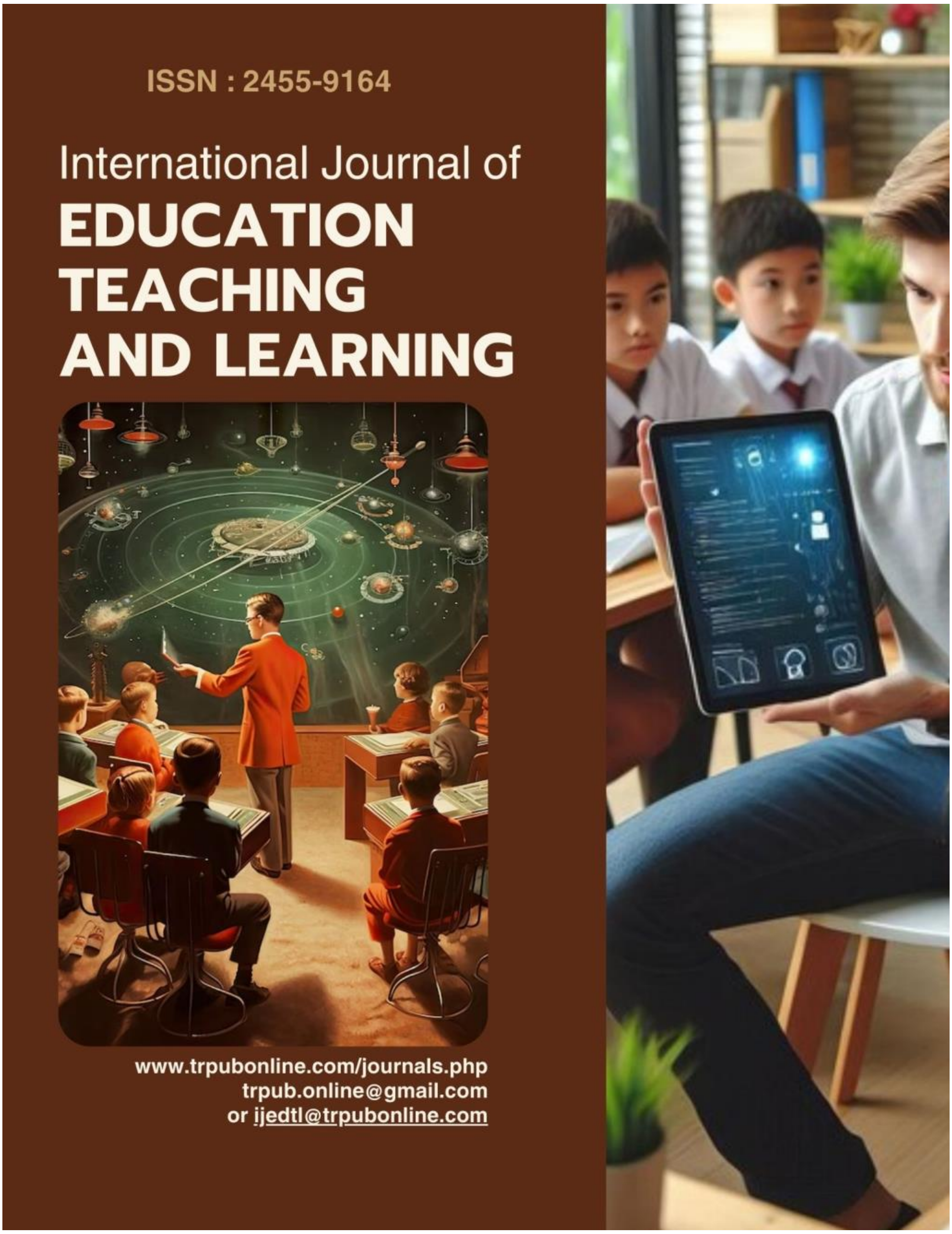
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Teaching–learning sequences: aims and tools for science education research

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An important area of research that has been going on since the 1980s is on scientific education via the development and execution of topic-oriented sequences rather than comprehensive curricula. What sets a teaching-learning sequence (TLS) apart is its incorporation into an evolving process based on research that seeks to weave together the scientific and student viewpoints. This paper aims to accomplish two goals: first, it introduces the special issue and serves as an overview of recent trends and developments in TLSs and their classroom validation; second, it introduces the reader to this volume and helps them understand the processes of developing and validating research on TLSs by discussing empirical studies, theoretical proposals, methodological tools, and approaches to explaining the design of these sequences in plain language.

Introduction

Researchers have been creating different types of research-based instructional activities and methods to help students better understand scientific information, largely as a response to previous empirical studies that asked students to describe various phenomena and concepts, as well as theoretical advances that focused on teaching and learning as a constructive activity. An interesting field of research that has been going on since the 1980s is on developing and implementing scientific lesson plans for specific topics rather than whole curricula. These topics include optics, heat, electricity, fluids, respiration, photosynthesis, structure of matter, and electricity. Research in the field of science education has a history of focussing on smaller scales, such as individual sessions or sequences of topics, rather than larger ones, like entire curriculums (Kariotoglou and Tselfes 2000). Their two-pronged approach to research and development aimed at strengthening the connection between a subject's instruction and its acquisition is a defining characteristic of these types of exploratory activities and products. Such lesson plans essentially follow in the footsteps of action research, which has long served as a foundation for innovative approaches to research and the solution of particular learning challenges connected to certain topics. The European research community has taken an interest in concerns raised by science educators about the nature of research integrated into lesson plans.

community by Lijnse (1994, 1995), who contends that this type of endeavour constitutes a form of "developmental research" entailing the interweaving of topic-specific instructional design, development, and implementation, typically spanning a few weeks, in an iterative evolutionary process illuminated by comprehensive research data. Following this, in 1995, Kattman et al. offered a framework for 'Educational Reconstruc-tion' that could be used to refine and enhance the design of teaching-learning sequences (TLSs). Note that Artigue (1988) proposed a useful theoretical framework for creating lesson plans in mathematics education that draws students' attention to an a priori epistemological investigation of the subject matter, a strategy that works just as well in scientific education. Later on, these three methods are refined. While other names have been proposed for this feature of research-based topic-oriented sequences, the term "teaching-learning sequence" (Me'heut and Psillos 2000, Psillos and Me'heut 2001) has recently emerged from international symposia and is now commonly used to describe the tight relationship between planned instruction and anticipated student learning.1 Teaching and learning strategies (TLSs) are both an intervention and a product, similar to standard curricular unit packages. They consist of teaching and learning activities that have been investigated and experimentally developed to match student thinking. In several cases, instructional materials can include anticipated student responses. Research into students' conceptions, characteristics of the particular scientific domain, assumptions about knowledge and learning, pedagogical practices, and educational context are all factors that appear to have an impact on the development of these TLSs. Researchers typically go into great detail on the student learning results from different TLSs in published articles. A TLS's design, its teaching features, and the interlacing of teaching and learning are not often discussed, and if they are, they aren't always made clear and understandable, in contrast to the extensive communication of learning results. Maybe journals don't have enough room for this, maybe there's a lack of generally acknowledged methods for portraying instruction, or maybe there's a lot of craft expertise involved in teaching and managing specialised topic (Fensham 2001). We conceived of this special issue in this setting, after international conferences on the same subject had been organised (see note). This introductory paper aims to accomplish two goals: first, to give a general outline of recent trends and developments in TLSs and their validation in the classroom; second, to introduce the reader to this volume and help them understand the research on TLSs and how it was developed and validated; and third, to discuss empirical studies, theoretical proposals, methodological tools, and approaches to explaining the design of these sequences in plain language.

Aclassificationscheme

One distinguishing characteristic of a TLS is its inclusion in a gradual research-basedevolutionaryprocessaimingatinterlacingthescientificandthestudentperspective.
In the present paper we attempt to discuss and bring together two of thesteps involved in experimenting with a TLS, namely design and validation. Oursampleconsistsofseveralsequencespublishedinvariouscountries,althoughwedo

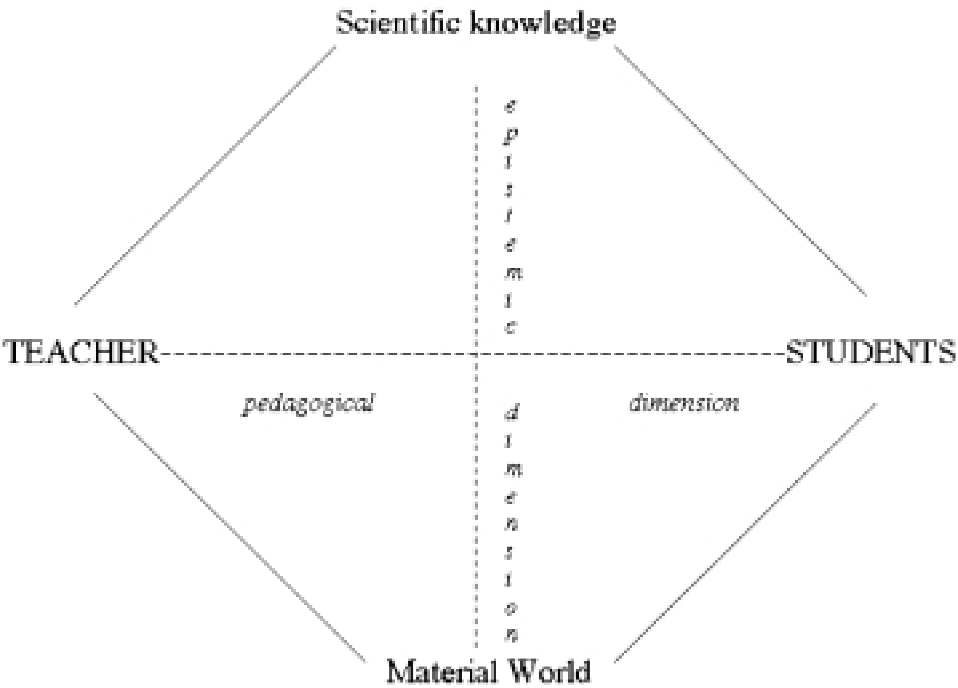

Figure1. Thedidacticalrhombus.

not claim to cover the field comprehensively. We endeavour to reveal certain trends,drawing on different research traditions, from both well-known and less familiarpublications, so as to enrich the public discussion on TLSs. Some TLS studies,surprisingly,seemlargelyunawareofotherswithwhichtheysharecommonperspectives and assumptions. In this *a posteriori* classification, we use the recentlysuggestedterm 'teaching–learningsequence'acrosstheboard,regardlessof theterms originally used by the various authors. In doing so we are cognizant of the factthat certain of the studies reviewed involve aspects of TLSs focusing on differentlevels: for example, some studies may deal with the micro-level of a few tasks withinasequencewhileothersprovideoveralltreatmentofanentiresequence.

On the first point, that of design, we will focus on the main considerations putintoplaywhendesigningaTLSastheseemerge,implicitlyorexplicitly,fromseveralstudies. The discussion will focus on issues like the design of teaching–learningsituations,problems,activities,thepartplayedindecisionsbyavarietyofconsiderations including content analysis, epistemology, students' conceptions andmotivations,learningandpedagogicaltheoriesandeducationalconstraints.Wetryto organize this diffuse mass of considerations using a two-axis 'didactical rhombus'as presented in figure 1. In this schema, the vertical axis represents the 'epistemic'dimension (i.e. how knowledge works with respect to the material world) and thehorizontal axis the 'pedagogical' dimension (i.e. the choices about the respectivepartstobeplayedbyteacherandclass).

Along the epistemic axis, for example, we find assumptions about scientificmethods, the processes of elaboration and validation of scientific knowledge thatunderliethe design of the sequence.Along the pedagogical axis, we willfind choices regarding the function of the educator, the nature of the relationship between the educator and their pupils, and, at the 'Students' vertex, the dynamics within the student body. We will align students' understandings of physical events with the 'Students-Material World' side, and closer to the 'Students' vertex, we will find more generic, spontaneous forms of thinking. The 'Students- Scientific Knowledge' side will display students' perspectives on scientific knowledge. This visual depiction shows how the epistemic and pedagogical aspects of a TLS may be separated and organised, which is helpful when thinking about how to construct one. We learn more about the relationship between the TLS's epistemological and pedagogical components when we combine the two aspects. From what we can tell from the research we looked at, some place more emphasis on the epistemic component, others on the pedagogical, and still others on the interwoven elements. Researchers often just provide generic descriptions and do not elaborate on how they account for contextual issues, such as educational limits. Therefore, we will exclude contextual elements from our study and concentrate on the epistemic and pedagogical aspects in this review. Part two of the article will go into the several ways these TLSs may be validated. Validation of the choices or hypotheses underpinning the design of activities, as well as the efficacy of the sequence with respect to certain goals, will be the primary focusses of the study technique. It will become clear that there are primarily two schools of thought. The first one is similar to "production engineering" in that it emphasises the viability and efficacy of a worldwide curriculum design. In contrast, the second kind of study is closer to "experimental research," using a more analytical approach to describe learning processes and test hypotheses. Whether these two methods can be enhanced simultaneously is something we'll talk about.

DesigningTLSs:sometrends

It seems that we may encounter some difficulties in reconstructing the historicaldevelopment of research on TLSs, perhaps because in the early steps of thedevelopment of science education research attention was focused on students'conceptionsandwaysofreasoning.Itmaybethatsomelessstudent-centredpointsof view were difficult to publish and have remained more confidential, theirdiffusionlimited.Wewill,however,trytocharacterizesomeinterestingtrendsandtosituatethesetrendswithrespecttoourdidacticalrhombus.

Apsychologicalconstructivism?

Duringthe1970sandearly1980s,theaccentwasonresearchintothe(mis)conceptions, representations and spontaneous reasoning of the learner. Thequestionnaturallyaroseastohowtotakesuchpiecesofinformationintoaccountin order to improve science teaching and learning. One current, which resulted inresearch-based teaching approaches, was strongly 'learner-centred', emphasizingthe students' resources and the potentialities of confronting their ways of reasoningwithdatafromthematerialworld(DriverandOldham1986).

Such approaches could be situated on our didactical rhombus in proximity tothe 'Students–Material World' side, the attention paid to the teacher's role beinglimitedandtheepistemicpointofviewpoorlydeveloped.

Comprehensive reviews of the considerable amount of research work developedin this perspective can be found, for example, in Scott et al. (1992) and in Duit(1999).

Answers to the question already expressed range from the radical constructivistto the moderate. In the radical responses, the teacher's role is mainly to establish afavourable climate for student discussions and activities, the students being largelyresponsible for formulating and solving problems themselves. This point of view isexpressedbyVonGlasersfeld:

> Theteacher'sart[...]residesingettingstudentstogenerateproblemsoftheirownthatareconducivetoth ewaysofthinkingthataretobetaught.(1992:37)

Italsoappearsinproblem-posing approaches:

> In other words: preferably the students themselves should pose the problem to be furtherinvestigated [. . .] they themselves frame the questions that drive their learning processes.(Kortland2001:9–10)

Thistypeofmodelfocusescloselyonthestudents,andontheroleoftheteacherasafacilitatorofstudenta ctivities.Majorchoicesunderlyingthedesignof thesequenceareindependentofthespecificdomainofscientificknowledge.

In less radical approaches, the teacher (or researcher) is in charge of elaboratingthe problems to be solved; as we will see, this can lean more towards psychologicaljustification or epistemological argument. Here, we consider one main approachthatgivesgreatimportancetocontradictions.Afirstsetofresearchwork(see,forinstanc e, Dewey and Dykstra 1992, Driver and Bell 1986, Driver and Erickson1983, Nussbaum 1989, Nussbaum and Novick 1982, Ravanis and Papamichael1995)putstheaccentonclarificationofpupils'ideaswheninterpretingorpredicting the results of experiments and 'destabilization' of these incorrect ideaswhen confronted with contradictory observation. Other authors use the word'conflict' to describe the contradictions between individual pupils' different thoughtprocesses(RebmannandBugeat1994,StavyandBerkovitz1980).Anothersourceof conflict can be found in the contradictions between the thought-processes ofdifferentpupils(Champagneetal.1985).

Letusnotethat,restrictingourselvestothedidacticsofphysicsandchemistry,it is difficult to evaluate the advantages and limits of such 'conflict' strategies. Ifsome studies conclude the effectiveness of such strategies (Guzetti et al. 1993), thisconclusionisnotfullyshared.Nussbaum(1989)questionstheseteachingstrategies,statingth at 'thestudentsmaintainsubstantialelementsoftheoldconceptions'(p.538),whileSchwedesandS chmidt(1992)andScottetal.(1992)go a step further, questioning the way in which pupils recognize these programmed'conflicts' and how they resolve them (Chinn and Brewer 1993). These researcherstouch upon two important issues. The first is that what researchers consider a'conflict situation' is not necessarily such for the students, at least with regard toexperiments. Examples from teaching electricity are illuminating in this respect(Koumaras et al. 1997, Psillos et al. 1987). The second issue is that, in a number ofcases, the data gathered tend to assess the global effectiveness of a teachingsequencerather than permit precise analysis of the setting up and development of a specific conflict (see later). Although the high expectations of conflict strategieswerenotfulfilled,appropriateembeddingofconflictsituationsina TLSmayimproveitseffectiveness.

Anepistemicconstructivism?

Our paradigm characterises the second school of thought among research-based strategies for scientific education as holding the epistemic point of view. Rather than focussing on the needs of educators and students, we will provide an overview of some of these techniques that are primarily based on the scientific content that has to be generated. There are several facets of scientific knowledge that might motivate students to study. Such TLSs have been created in the area of electro-kinetics, namely employing hydraulic (Schwedes and Dudeck 1996, Schwedes and Schmidt 1992) and thermal (Dupin and Johsua 1993) analogies, while some techniques depend on the usage of analogies across distinct disciplines of knowledge. Others rely on knowledge fragments being analysed to solve difficulties. These methods improve the connection between the issues and the information that can solve them. Once again, the goal is to show students the limitations of their current thinking processes and encourage them to generate or appropriate new information by having them solve well-designed tasks (such as prediction questions). It seems that these methods have not produced many scholarly articles that have been published on a global scale. This might be the reason why some writers believe that the focus of current research in science education is not on the scientific substance (Fensham 2001, Lijnse 1995). Here, we'll use a few examples from French literature both at home and abroad to demonstrate this method. By manipulating several elements, Tsoumpelis (1993) plans to construct the concept of molar concentration via prediction problems involving variations in osmotic level. As part of a series on free fall in mechanics, Robardet (1995) predicts the motions of two objects with different masses as they fall; the remainder of the series is organised around the search for a connection between the falling object's speeds at various points in time. Weil-Barais and Lemeignan (1990) investigated this kind of issue, which is the pursuit of a connection between distinct ideas, in regard to the quantity-of-movement notion. By constructing energy-transformation chains, the same authors (Lemeignan and Weil-Barais, 1994) suggest energy-related training exercises, such as extending the life of a light bulb while simultaneously increasing its brightness or powering a tiny vehicle with a combination of a battery, a hair dryer, a pressure cooker, the sun, and so on. Representational tasks that attempt to characterise the devices' operation in terms of energy transfer supplement these action issues (the generation of such and such an effect). Learning can be driven by a variety of problems, including prediction problems (the focus of research into "cognitive conflicts"), action problems on material systems (producing, modifying an effect), or more "theoretical" problems (how to represent different phenomena in a unifying manner, how to establish a relationship between physical quantities, etc.). The goals of scientific activity are not so much the confirmation (or rejection) of theory but the development of ever more robust models, which is consistent with an instrumentalist perspective on research and such methods. Regarding this aspect of the model of view, problems are useful not only to solve contradictions, but also to developmodelsassimpleandpowerfulaspossible,inordertoexplainseeminglydifferentphenomenainaunifyingmannerandtosupportactionandprediction.

Asmentionedearlier,suchapproachescouldbesituatedonourdidacticalrhombusvery closetotheverticalaxis:thedrivingforcesoflearningaresoughtfromthe epistemic significance of knowledge. It is more or less implicitly supposed thatsuchepistemicdrivingforcescanactasforcesdrivinglearning.

Towardsanintegratedconstructivism?

Even in the early 1980s, these two registers—the psycho-cognitive and the epistemological—were noticeable. Analysing the students' prior knowledge informs the selection of experiments (and questions) in such early approaches. The educational goals are narrowly defined, with the 'notions' covered in context with the underlying scientific principles. As a result of referring to both students' prior knowledge and scientific understanding, researchers are able to suggest novel ways of thinking about the phenomena under study, which might not necessarily align with what is taught in school. As an example, in a study on teaching concepts of heat and temperature, researchers Tiberghien and BarbouX (1983) and others suggest manipulatives to help students understand the relationship between a substance's temperature and its thermal balance (p. 7). They also encourage students to generalise the idea that all substances experience an increase in temperature when heated, excluding change of state. page 7. Despite its apparent simplicity, the information that students will gain here represents a significant departure from their previous beliefs. For instance, it appears that students previously held the belief that the temperature of certain substances (such as ice and sand) is constant. Similarly, Se're' and Chomat (1983) raised doubts about their depiction of a gaseous state and proposed instructional scenarios where students are asked to assign specific properties to the gases, focussing on weight and the conservation of quantity during various transformations. Such research was a major milestone in the development of TLSs, which aim to adapt to students' reasoning by defining their initial cognitive state according to what is known from current research and then defining their desired final cognitive state according to what is known from scientific knowledge. While this only provided a partial answer to how the educational process is described in relation to this end goal, it is worth noting that the importance of creating conditions that are "favourable to the pupils' expression of conceptions and their evolution" was emphasised (Tiberghien and BarbouX 1983: 5). A comparable strategy is present in more current research, which focusses on the student and attempts to characterise the relevant information. Because the researchers in these studies see the scientific material as problematic, they approach it in a manner that they believe will lead to new representations of scientific ideas and their connections that align with the purposes of education. In a constructivist sequence on fluids, the concept of pressure is presented at the junior high school level as a fundamental idea. Students are required to differentiate between pressure and force before learning about the latter, and then they are asked to create the connection force/pressure (Kariotoglou et al. 1995, Psillos and Kariotoglou 1999). Another research introduces voltage as a key component in asequenceonelectriccircuitsatjuniorhighschoollevel,whereascurrentintensityis generally the introductory primary concept in school curricula (Psillos et al. 1988;Tiberghien et al. 1995). Differentiation of the concepts of intensity, tension andenergy is a prominent objective of this sequence, in which the experimental fieldincludesthedurationofabattery,unliketheusualpatternwhereonlybrightnessistr eated. In another sequence on introductory electricity, Barbas and Psillos usedtransient states of electrical circuits in order to compensate for the observeddissociationofelectrostaticandelectro-kineticphenomenabythestudents,takingintoaccounttheircausalthinkingaswell(Bar basandPsillos1997)

Several other examples may be also cited, concerning traditional topics likeoptics (Chauvet 1996, Galili 1996, Kaminski 1991) at junior high school level,energy(Trumper1990),structureofmatterandparticlemodels(Méheut1997, MéheutandChomat1990,Scott1992,Vollebreght1998)or,morerecently,superposition principle (Viennot and Rainson 1999), and modern topics like non-linear physics in upper school physics classes (Komorek et al. 2001), fuzzy topicslike the introductory treatment of errors at university level (Evangelinos et al. 2002)orcross-disciplineonesliketides(ViiriandSaari2004).

Wemayobservethatsomeoftheseapproachesgiveasignificantroletocontradiction as a source of motivation for learning, while others are more explicitlymodelling-oriented (Gilbert and Boulter 1998). We can see here an expression ofdifferentepistemologicalpointsofview;onemorelogical,theothermoreinstrumentalist.

Among the numerous studies on the use of analogies (see, for example, Arnoldand Millar 1996, Duit 1991, Glynn 1991), we find some that are mainly knowledge-centred, resting on an analysis of similarities between domains, and others that aremore integrated, taking into account both psycho-cognitive data about the studentsand epistemic analysis about the analogical structures of the knowledge in question.Bridging analogy strategies can also be considered as belonging to this type ofintegratedconstructivistapproach(Brown1994).

Suchapproachesmaybelocatedonourdidacticalrhombustotherightofthevertical axis, interlacing considerations about the students, their relation to materialworld,andepistemicpointsofview.

One important remark about these and previous studies is that they pay littleattention to the role of the teacher. Let us remark that recent pieces of researchwork, in a Vygotskian approach, plead for more attention to be given to this aspect(Dumas-CarréandWeil-Barais1998,LeachandScott2002).

ValidatingTLSs:sometrends

If we look at the utilization of a sequence as a teaching and/or research tool, variouskinds of validation appear. Some methodological approaches aim at evaluating theeffectiveness of a sequence by comparing the students' cognitive 'final state' withtheircognitive'initialstate'.Otherapproachesilluminatestudents'cognitivepathways allthroughtheteaching–learningprocess.

Pre-test/post-testprocedures

The methodology often adopted tends to prove the effectiveness of a teachingpackageinrelationtospecificlearningobjectives.Datacanbecollectedintheform of tests carried out after the sequence. The effectiveness of such an approach can befoundbycomparingtheseresultswiththoseobtainedbythesamepupilsbeforethesequence(sometimescalled‘internal’evaluation)orbythoseofagroupofpupilsjudged to be of the same level and who have not attended the same sequence(sometimes called ‘external’ evaluation). The first objectives of internal evaluationsaretotesttheeffectivenessofthesequenceinrelationtotheinitialobjectives(see,for example, Andersson and Bach 1996, Asoko 1996, Boohan 1996, Mortimer1993, Thiis 1992). ‘External’ evaluations allow us to ascertain that, in relation toour objectives, work done together with the pupils is more effective than other typesof teaching taken as reference (see, for example, Chang and Barufaldi 1999,Kariotoglouetal.1995,Minstrell1992,Nikolopoulou1993,Psillos1998,Ravanis andPapamichael1995).

Internalorexternalevaluationshavealsobeenusedtocharacterizetherelativedifficulty of a given objective. Thus, Tiberghien and Barboux (1983) concluded,aftersuchasequence,thatthenotionofthermalequilibriumisdifficulttoacquirein the junior secondary school years, although the fact that the temperature does notvarywhenthereisachangeofstateprovestobelessofaproblem.Later,Chauvettried to characterize the ‘obstacles and persistent difficulties’ at the end of a teachingsequence on colour, ‘persistence of the common conception of colour as matter’and ‘fragility of the conceptualisation of coloured light’ (1994: 179). Conceptualprofiles can be considered as fruitful evaluation tools in this perspective (ViennotandRainson1999).

Suchtypesofevaluationgeneratethefollowingquestions.

- Some cognitive objectives prove to be easy or difficult to reach, but can suchresultsbeconsideredasgeneralandindependentoftheconditionsinwhichtheyhavebeenobtained?
- Whichchoicesinthedesignofthelearningsituationsaredeterminantfortheeffectivenessofthelearningprocess?Inthegapbetweenusualtypesofteachingandexperimentalteaching,whatactuallymakesthedifference?

Hereweencounterproblemsrelatingtothecontrolofvariablesandthereproducibilityofexperimentalteaching.Ifthesequestionshavebeentheobjectofdidacticalstudiesinmathematics (Artigue 1984, Brousseau 1981), it seemsthattheyarelatentinthedidacticsof physics and chemistry. In the past fewyearstheyhaveappearedindeclarativeratherthanoperationalformin inter-nationalpublicationsinthedidacticsof physics. Thus, Hewson and Thorley(1989)remarkthatifthemodelof‘conceptualchange’hasbeensetinmotioninnumerousteachingsequences,the data thus gathered were insufficient topermitdiscussionoftherole played by the specific factors considered asessentialinputtingthismodelinto effect. The precautions taken by certainauthorsinpresentingtheirconclusionsshow that they share these preoccupa-tions. Thus,JohsuaandDupin(1989:201)betonthereproducibilityoftheirobservations, whereas Rainson (1995: 152) leaves the issue open. Andersson andBach (1996) formulate the problem clearly in relation to their ownexperiments:

> Thereis,however,onequestionthattheimproveddesigndoesnotanswer.Whichaspectsoftheteachingwereparticularlyimportant,andwhichwerelessimportant,withreferencetoachievingtheobservedresult?(p.18)

Studyinglearningpathways

Another type of approach that has gained prominence in science education researchconsistsofobservingpupilsallthroughthelearningprocess.Thisseemsindispensable if we want the study of the learning processes to be focused and to testthechoicesmadeintheelaborationofspecificteaching–learningsituations.

Wecanfindthispreoccupationinsomeearlystudies(see,forexample,Méheut 1982,Séré 1985,Tiberghienand Barboux 1983)thatincludedobservations, collected as manipulation memos and written answers to teachers' questions ortests. Such an initial preoccupation is further elaborated in more recent works interms of the description of cognitive itineraries, conceptual pathways or learningpathways (see, for example, Arnold and Millar 1996, Aufschnaiter and Welzel 1999,Duitetal.1992:part3,Galili1996,Niedderer1997,PetriandNiedderer1998, PsillosandKariotoglou1999,Welzel1998).

Detailed analyses of students' learning pathways can be used to discuss theeffectivenessofaspecificlearningsituation,inadditiontotheoverallevaluationofasequence,totesthypothesesunderlyingthedesignofthelearningsituationsandtoimprovethem.Forexample,adetailedanalysisofastudent'slearningpathwayallows Schwedes and Schmidt (1992) to discuss the reality of expected cognitiveconflictsandtobringtolightsomeunexpecteddifficultiesencounteredindevelopingananalogybetweenhydraulicandelectriccircuits;PsillosandKariotoglou (1999) traced the various learning pathways of students who wereengaged in a teaching sequence in fluids, and thus accounted for their differentialreaction to a conflict situation. We find similar kinds of results in Arnold and Millar(1996), regarding the use of an analogy in the teaching of heat, temperature andthermal equilibrium, and in Duit et al. (1998), regarding the use of an analogy inaunitonchaoticsystems.

Aswewillseefurther,suchresearchpresentssomecharacteristicsofwhatLijnse (1994) defined as 'developmental research': data analysis makes it possible todiscussandimprovetheeffectivenessofteaching–learningstrategies–see,forinstance, the evolution of strategies between Schwedes and Schmidt (1992) andSchwedesandDudeck(1996).

Collectingthecontributionsofvarioustheoreticalandmethodologicalframeworks

Inthepreviousparagraphswehavetriedtoillustratesometrendsinthedevelopment of specific TLSs and ways of validating them that have been used inseveral studies. In addition to a number of topic-oriented sequences, an importantdevelopmentinthisfieldisthepublicpresentationofgeneralframeworksfocusingonthefactorstakenintoaccountandprocessesinvolvedindesigningsequencesas a research activity. We now outline some of these general frameworks, whichprobably reflect different research traditions and educational contexts, in order toillustrate their specific contributions in the discussion on TLSs as well as theirpossiblecommonpointsordifferences.

About'DevelopmentalResearch'

General issues concerning the place of TLSs in science education research werebroughttotheforeintheareaofEuropeanphysicseducationwithPietLijnse's papers on 'developmental research' (Lijnse 1994, 1995). Surprisingly, or perhapsunaware of some still barely perceptible research currents (see earlier), he talks of'thealmostcompletelackofattentiontosciencecontent'incontemporaryresearchinscienceeducation.Healsodoubtswhethergenerallearningor pedagogicaltheories may prove useful when it comes to the level of specific topic-orienteddesigns. In order to 'fill the gap between theory and practice', Lijnse proposed ageneral schema for developing 'didactical structures'. Starting from Freudenthal'sposition, Lijnse attaches great importance to the freedom of students to follow theirownelaborations.Heconsidersthat'conceptualchange'and,particularly,'cognitive-conflict' strategies do not give students this opportunity. The problem isthenformulatedas'toconceiveteachingsituationstoleadstudentstobuildfreelytheideaswewanttoteachthem'.

Lijnse proposes some guidelines for designing such teaching–learning situa-tions.Intheseguidelines,greatattentionispaidtothemotivationalandmeta-cognitive dimensions and to the learning on the part of the teachers made necessaryby such an approach. Some general indications concerning conceptual developmentare given, with three suggested levels: selection of focus, transition to a descriptivelevel and, if necessary, transition to a theoretical level. Referring to this framework,Kortland(2001)proposestodeconstructtheteaching–learningprocessintofivephases:motivation,question,investigation,applicationandreflection.

PietLijnsegivesgreatimportancetoempiricregulationintheprocessofelaborating 'didactical structures'. Such regulation starts from a scenario describingand justifying (*a priori*) the design of teaching–learning activities and the expectedteaching–learningprocesses.Theteachercanusesuchascenariowhenpreparingtheclassroomtrial,anditisalso aguideforclassroomobservationsintheperspectiveofproducing didacticalstructures 'good enough for teachingpractice'.

About'EducationalReconstruction'

The model of 'educational reconstruction' developed by Kattmann et al. (1995)provides a framework for designing and validating TLSs that draws on planninginstruction models that were developed in the German pedagogical tradition. Themodel attempts to combine the German hermeneutic tradition on scientific contentwith constructivist approaches to teaching and learning. It holds that clarification ofscience subject matter is a key issue if instruction in particular science content is tobe developed. This is a process called 'elementarization', which leads to construct-ing the core ('elementary') ideas of the content to be taught. Often this clarificationprocess is primarily or solely informed by issues coming from the structure of thereferent science content. Educational issues are then regarded only after the sciencesubjectmatterhasbeenclarified.Thesignificantfeatureoftheeducationalreconstruction approach is that its analysis of science content takes into account notonly epistemic dimensions (genesis, function and meaning of the concepts), but alsocontext,applicationsandethicalandsocialimplications.

The educational reconstruction model closely links considerations on thescience concept structure with analyses of the educational significance of thecontentinquestionandwithempiricalstudiesonstudents'learningprocessesandinterests. Students' conceptions are taken into account in a constructive perspectiveinreconstructingsciencecontentstructureby providinganswerstoquestionslike

‘Whicharethemostrelevantelementsofthestudents’conceptualframeworktoberespected? Whichopportunitiesareopenedbycertainelementsofstudents’conceptions or perspectives? Which conceptions of students correspond withscientific concepts in such a way that they can be used for a more adequate andfruitfullearning?’(Kattmannetal.1995).

Themodelisbasedonanintegratedconstructivistview.Ontheonehand,the knowledge acquisition process is seen as an active individual constructionprocess within a certain social and material setting, while science knowledge, onthe other, is viewed as a tentative human construction. Results of the analysis ofcontent structure (linking clarification of the core concepts and analysis of theeducational significance) and preliminary ideas about the construction of instruc-tionplayanimportantroleinplanningempiricalstudiesonteachingandlearning. The results of empirical studies influence the processes of educationalanalysis, elementarization, and even the setting of detailed goals and objectives.This procedure is rather unusual for educational research, yet it fits the situationthataparticularcontentstructureforinstructionhastobedevelopedaccordingto the students’ point of view, and especially according to their pre-instructionalconceptionsandtheirlearningpaths. Thesciencecontentstructureandthestudents’ conceptions and frames of interpretation are seen as being equallyimportantparametersintheprocessofeducationalreconstructionandarenecessaryfortheachievementofthegoalsofscienceteaching.Aspecialcharacteristic of the model is that knowledge gained in one of the componentsinfluencestheactivitiesandtheinterpretationoftheresultsoftheothercomponentsinadynamicprocess.

About‘IngénierieDidactique’

Another framework that was developed in mathematics education research is, as wementioned earlier, also useful for science education. This framework proposedguidelines for both designing and validating a sequence. In this general framework,Artigue(1988)suggestedthreemaindimensionsfor*apriori*analyses:

- an‘epistemological’dimension:analysingthecontentstobetaught,theproblemstheyanswer,theirhistoricalgenesis;
- a‘psycho-cognitive’dimension:analysingthestudents’cognitivecharacter-istics;and
- a‘didactic’dimension:analysingthefunctioningoftheteachinginstitution.

This general framework rests on a strong model of learning by problem-solving.Thus, the *a priori* analyses are interlaced in order to accurately define ‘problems’ tobe managed by students and to anticipate the elaboration of knowledge by studentsthroughthese‘problems’. Thecomparisonofthecognitiveitinerariesactuallyobserved with those predicted can validate or challenge the hypotheses involved inthebuildingupoflearningsituations.

DesigningaTLS

We may situate the features of these three frameworks with the help of our didacticalrhombus:students,materialworld,scientificknowledge,teacher.

In the framework of developmental research, Lijnse (1994, 1995) focusesmainly on students and only secondarily on the role of the teacher; the epistemicdimensionsoftheknowledgetobetaughtarenotevokedasplayingadetermini ngpart in planning the didactical structure; problems are to be formulated by thestudents,withthehelpoftheteacher;onlygeneralindicationsaboutaprogressionare givenbytheresearchers.

Both'IngénierieDidactique'(Artigue1988)and'EducationalReconstruction'(Katt mannetal.1995)suggestpreciseguidelineswithregardtotheepistemicdimension.In'Ingé nierieDidactique'theelaborationofproblemstobetreatedis the responsibility of the researchers, and is strongly linked to content analysis. Asalready mentioned, Artigue focuses on *a priori* analyses: epistemological, psycho-cognitive(conceptionsandreasoning),and'didactic' (educational constraints),while little is said about the psycho-affective and social aspects of teaching–learningprocesses. In 'Educational Reconstruction' we can also find content and psycho-cognitiveanalysis,aswellasmuchaboutmotivationandthesocialandethicimplicationsoft heknowledgetobetaught,butlittlediscussionofeducationalconstraints.

Thus,thedevelopmentalresearchframeworkappearstobemorepsycho-logicallybased,andthedesignofactivitiesstudent-centred,whereasin'IngénierieDidactique' epistemic points of view appear more explicit. 'Educational Recon-struction' can appear as taking into account quite explicitly psycho-social points ofview and epistemic analyses and their interlacing. We note that our remarks reflectwhat the authors say about the relative emphases in their frameworks, and do notimplythatotheraspectsareignored.

Wemaynotethatcertainfeaturesarecommontoallthe theoreticalproposals and empirical studies: on the one hand, the treatment of the usualscientificcontentasproblematicinrelationtotheaimsofinstruction asperceivedbythedesigners,andontheotherthedynamiccharacterofthedevelopment of a TLS, the features of which are further discussed in the nextsection. This means that designing a TLS is not a 'one-shot' activity, but a long-term endeavour, one product of which is often an innovative content representa-tion,whichisdifferentfromthoseappearinginnumeroustextbooks andcurriculaworldwide.

With regard to empirical research, we note that some factors could or should bemore explicitly taken into consideration in the design of a TLS. This is the case witheducational constraints, which are rarely explicitly managed or even reported(Tiberghien 1996). In other words we argue that researchers should make public thecraft handling of contextual factors and particularly educational constraints. Webelieve that this is a difficult endeavour bearing on the feasibility of TLS beyondsmall-scale innovation. This is also the case with managing social interaction in theclassrooms,afactorthathasonlyrecentlybeguntobetakenexplicitlyintoaccount inthedesignofTLSs(Dumas-Carré andWeil-Barais1998, Leach and Scott 2002).

We consider that the features and processes that one researcher may take intoaccount in designing his/her TLS may vary according to personal preferences andcontexts. However, we suggest that a challenge for the future in this field isclarification of the assumptions, or even distinction of the frames, that are taken intoaccount in designing a TLS. In other words, we plead for more 'frame-based'researchanddevelopmentonTLSs.

ValidatingaTLS

We discuss here certain perspectives concerning empirical regulation in the processof elaborating a TLS. As pointed out all through this paper, empirical regulation isintimatelyrelatedtodevelopingaTLS.Fromboththetheoreticalframeworksandthe empirical studies there emerges a long-term design, remote from a 'one-shot'endeavour,thatmayinvolvedifferentfociofvalidation,eitherbetweenthevariousTLSorbetweensuccessivetrialswithinaTLS.

Fromthe'DevelopmentalResearch'and'IngénierieDidactique'frameworks we will retain the notion of a teaching–learning scenario and the idea of comparingstudents'actualcognitivepathwayswithanticipatedones.Such a comparisonmakes possible an effective empiric regulation procedure, aimed at reducing theobserved deviations from the expected evolution undergone by the students; it canalsoprovideopportunitiesforthevalidation,orrefutation,ofcertainprecisehypotheses underlying the design of a TLS and/or specific situations included withinit. In other words, a scenario may be a useful tool for checking the validity of 'local'hypotheseswithinthecontextofaglobalTLS.

In the perspective of 'Developmental Research', the results of experimentingwith a TLS can be seen as 'adequate didactical structures', 'good enough teaching–learning processes', and so on. Strong emphasis is put on empirical regulation of theprocessofproducingsuchdidacticalstructures.Intheperspectiveof'IngénierieDidactique', the emphasis is on validating or challenging hypotheses involved in thebuildingupofdidacticalsituationsbycomparingthestudents'actualcognitivepathwaystoanticipatedones.

We argue that it is fruitful to situate these two perspectives with regard to twomain methodological paradigms for using TLS in a research perspective, the firstmore'productionengineering'orientedandtheotherleaningmoretowards'experimentalresearch'.Wewilltrytodemonstratehowcomplementarytheycanbe. Demonstrating the feasibility or effectiveness of a sequence can be linked to thepragmatic perspective of developing 'good educational products'. Trying to achieveprecisedescriptionsofstudents'cognitivepathwaysandtotestcertainspecifichypotheses can be linked to a perspective of understanding cognitive processes andtesting learning theories. In order to make the distinction clear, we can also thinkabout the following assertions: 'A sequence can be very effective without our reallyknowing why' . . . or . . . 'A sequence can be less effective but experimenting allowsus to know why'. . . or . . . the best . . . 'A sequence can be very effective and weknowpreciselywhy'.Soexperimentingwitha TLScanleadtotwotypesofinteresting results: results in terms of pragmatic value (feasibility, effectiveness, etc.)and/orresultsintermsofscientificvalidity(understandinglearning processes,testinglearningtheories,etc.).

Weconsiderthat,forsomeresearchers,theaimsofexperimentingwithaTLScanbe more on the 'production engineering' side and, for others, on the 'experimentalresearch'side(Méheut2001).Wesuggestthatthesearenotcontradictory,andcanbeattemptedwithinasinglepieceofresearch.Inouropinion,tomakesuchaimsasclearas possible and to elaborate consistent methodological approaches for dealing withthem in an adequate manner constitutes an important challenge for science educationresearch today. It would allow researchers to answer both the requirements we face:that of pragmatic value and that of scientific validity. We hope that this special issuewillcontributesignificantlytothisproject.

Presentationofthecontributionstothisspecialissue

This introductory overview is one of six articles that make up this special volume; the others showcase various research perspectives on the topics covered in this paper and span a broad variety of topics. In a range of educational settings including students from lower and upper secondary schools as well as universities, the writers present or debate TLS that pertain to different areas of scientific knowledge. The subjects covered include common ones such as the structure of matter, fluids, optics and conductivity, solubility, changes of state, thermo-elastic properties of gases, important new phenomena, non-linear systems, and new issues related to scientific literacy. The authors of the various topics are Lijnse, Klaassen, Me'heut, Psillos, Tselfes, and Kariotoglou; Buty, Tiberghien, and Le Mare'chal; Kabap'ınar, Leach, and Scott; Me'heut, Klaassen, Me'heut, and Me'heut. The authors of the various topics have contributed to the topic. The papers primarily address theoretical framework-related topics such as developmental research (Linjse and Klaassen), new theory-based tools for designing and analysing TLSs at both the macro and micro levels (Buty, Tiberghien and Mare'chal), modelling the didactical activities of existing TLSs (Psillos, Tselfes and Kariotoglou), a retrospective discussion of TLS development in relation to theoretical frameworks (Me'heut), new research methods (Komorek and Duit), and a discussion of innovation feasibility (Kabap'ınar, Leach and Scott). Notably, the researchers examine preexisting TLSs—created gradually by themselves and colleagues—from different theoretical vantage points in several of the articles. Future study may be more theory-based if such a posteriori talks are successful in capturing the craft knowledge involved in the creation and development of different TLSs. "Doctrinal structures" are one potential result of TLS research, according to Linjse and Klaassen. The study focusses on the didactic quality of the problem-posing technique, an explicit didactical viewpoint, and how it may be used to teach and learn a given subject in the classroom. In the broader framework of developmental research, they lay out three instructional frameworks that are based on a problem-posing approach. A research scenario is central to this framework because it provides a detailed prediction and theoretical basis for the proposed teaching-learning process. Recent research on scientific activity provides the theoretical groundwork for an epistemological model of teaching and learning activities proposed by Psillos, Kariotoglou, and Tselfes. The pillars upon which this structure rests are the following: Cosmos, Evidence, and Ideas. Three TLSs in the fluids area were developed over several years by the same researchers under a succession of changing dominant approaches to science education (transmission, discovery, constructivist), and they use this framework to model a posteriori the didactical activities included in each. Theoretical assumptions relating to learning, epistemology, and didactics form the basis of the instrument presented by Buty, Tiberghien, and Le Mare'chal. Models in physics and chemistry, as well as students' prior knowledge, form the basis of this framework, which in turn leads to the socio-constructivist design of lesson plans. Then, chemical and physics examples are used to illustrate the tool's use.

Méheutpresentsaretrospectiveanalysisoftwo TLSsonparticlemodels,describing the design process for each sequence. The development and evaluation ofthetwosequencesarediscussedwithrespecttogeneralframeworksfordevelopingTLSssuchas IngénierieDidactiqueandEducationalReconstruction,which provides an opportunity to clarify the similarities and differences between these twoframeworks.

Komorek and Duit explore the educational potential of non-linear systems inthe perspective of the Educational Reconstruction framework, which, *inter alia*,closely links analytical and empirical educational research with the development ofteaching and learning sequences. In the present paper the focus is on a teachingexperiment that has proven to be a valuable research method for investigatingteaching and learning processes. Teaching experiments may be viewed as Piagetiancritical interviews that are deliberately employed as teaching and learning situations.Thismethodthusappearstobewellsuitedforlinkingresearchanddevelopmentinthefir ststepsofdesigningteachingandlearningsequences.

Kabap´ınar, Leach and Scott report on a study addressing the teaching andlearning of the concept of dissolving at the secondary school level. The principal aimof the research was to investigate the feasibility of introducing a simple particlemodel of matter that students could use to make sense of the macroscopic andquantitative aspects of dissolving, thereby improving their understanding of thematter. A teaching intervention to fit within the existing chemistry curriculum wasdesigned, which explained macroscopic and quantitative aspects of solubility intermsofparticlesbyreferringtoasimpleparticlemodelofmatter.Tothisextent,at least, the teaching intervention met the requirements and restrictions of theexisting curriculum in Turkey. Findings suggest that while it is possible to design ateachingsequencethatintroducesasimpleparticlemodelofmatterinsuchawaythat students can successfully use it to explain various solubility phenomena,experimental subjects did not significantly outperform others, who did not follow it,in all aspects of the conceptual domain. The paper concludes with a brief discussionofthekindsofclaimsthatcanbesupportedfromastudysuchasthis.

Considering the elaboration of contents and the design of activities in thesepapers, we can see the importance given, on the one hand, to content analysis, withthe help of epistemology, and on the other to students' conceptions, common-sensereasoningandmotivation–theoneortheotherdimensionbeingmoreorlessdeveloped in the various papers. Thus, we find interesting contributions about thepart that epistemological considerations can play in the design of a sequence in thepaperspresentedbyButyetal.,Psillosetal.andMéheut.Inthesethreepapers,the knowledge to be taught is analysed from a 'modelling' point of view. The sequencespresentedbyMéheutaimathelpingstudentsconceptualizeatwo-levelworld, distinguishing and discussing links between macroscopic phenomena and micro-scopic models; Buty et al. also use a two-level scheme ('material world/theories andmodels'), while Psillos et al. propose a three-level scheme ('Cosmos–Evidence–Ideas').Itisimportanttonotethatinallthesepapersthe authorstakeintoconsiderationtheresultsofrese archconcerningstudentlearningdifficulties,common-senseconceptionsandwaysofreasoning.

Another issue emerging from such a confrontation of experiences concernsways of validating a TLS. We find real diversity here, both between the aims andbetweenthetypesofdataandtechniquesforobservingthe'effects'ofasequence.Thepointofvi ewdevelopedbyKabap´ınaretal.intheirpaperismainlyfocusedon thefeasibilityandeffectivenessofthesequencewithrespecttostudents' performance.I nherpaper,Méheutattemptstomakecleartwodifferentwaysof validating a sequence. The first, and perhaps the commonest, aims at proving theeffectivenessofasequencewithrespecttodefiniteobjectives;theother, lessusualap proach,istoobserveandtodescribethecognitivepathwaysofstudentsthroughthe activities composing the sequence. In a similar perspective, Duit treats thevalidityofteachingexperimentsasameansofinvestigatingteachingandlearning pr ocesses in the domain of chaotic systems. In these cases, data are collected duringsmall group (from two to four or five students) working sessions, with or without aninterviewer.

Note

1. An International Symposium and a Workshop on TLSs recently took place. Several of thepapers appearing in this volume were presented and discussed in an initial form during thesemeetings.ThefirsttookplaceinParis(MéheutandPsillos2000)andthesecondduringESERA2001(PsillosandMéheut2001).

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