A review of conceptual change research in science education
Una revisión de las investigaciones sobre el cambio conceptual en la educación científica

CARLOS SOTO-LOMBANA[1], JOSÉ OTERO[2], VICENTE SANJOSÉ[3]

[1] Departamento de Educación Avanzada, Universidad de Antioquia, Calle 67 # 53-108. Medellín-Antioquia, Colombia
[2] Universidad de Alcalá de Henares, Spain, [3] Universidad de Valencia, Spain.
csoto@ayura.udea.edu.co

Abstract

This article describes research done on conceptual change as published in four of the better-known science education journals during a 20-year period, from 1981 to 2001. The present review was focused at identifying three characteristics of that research: a) temporal distribution, b) research topics, and c) methodology: experimental designs and validity. The results show that much research work was carried out, although essential elements of Conceptual Change remained unclear. With respect to the methodology, we have evidenced scarce replication of previous studies, and an important number of studies that fall short of desirable validity levels.

Key words: Conceptual Change, Learning, Review, Science Education.

Resumen

Este artículo presenta los resultados de una revisión de la investigación de cambio conceptual hecha en cuatro de las más influyentes revistas internacionales, en el período 1981-2001. La revisión tuvo como fin establecer los siguientes aspectos: a) la distribución temporal de la producción; b) las áreas de investigación; y c) los aspectos metodológicos: diseños experimentales y su validez. Los resultados muestran que muchos de los aspectos teóricos del cambio conceptual siguen sin respuesta. Con respecto a la metodología, se evidenció un considerable número de estudios con bajos estándares de calidad científica.

Palabras clave: cambio conceptual; aprendizaje, revisión, educación científica.

INTRODUCTION

Research on science learning has repeatedly shown that students have conceptions associated to explanations of natural phenomena that clash with accepted scientific ideas. These misconceptions are remarkably similar among students from different cultures. The attempts in modifying these misconceptions evidenced the difficulties associated with this task. The entire modification effort was termed "Conceptual Change" (CC), and became a topic of research in itself. Studies on CC deal with how to change the non-scientific belief systems used by students to explain nature and how to turn these into scientifically valid knowledge. For this, attention is paid to the interaction between the learner's naive knowledge based on his/her everyday experience and new knowledge acquired through instruction.

CC studies originated in the early 80's as an outcome of research on alternative conceptions. Hewson (1981, 1982) and especially the Cornell group, composed by Posner, Strike, Hewson and Gertzog (1982) laid the cornerstone for research in this field. Thus, Posner et. al. (1982) used Kuhn and Lakatos's philosophical ideas about change in scientific theories as an analogy for conceptual change in an individual.

The seminal ideas (Duschl & Hamilton 1992) about CC, presented in Posner et. al.'s (1982) paper, were refined in the following years (Strike & Posner 1985; Hewson & Thorley 1989; Hewson & Hewson 1992), and even reformulated one decade after the initial article was published (Strike & Posner 1992). The original work was grounded in the philosophy of science. It gave birth to a research program (Kelly 1997) that analyzed changes in scientific theories in order to identify factors that facilitate or hinder the process of acquisition of scientific concepts by the individual.

Since then CC has evolved into an important research area dealing with teaching and learning science throughout the past two decades:

> Conceptual change undoubtedly has been the most powerful frame for research on teaching and learning science for the past 25 years... There is no doubt that the present state in the research domain allows to understand teaching and learning processes much better than in the beginning of the 1980s.(Duit 2002, p. 5).

In view of the above, a revision focused on the state of this research program and encompassing its 20 years of existence seems justified.

In continuation we shall list selection criteria used for choosing the sample of analyzed papers on CC in the area of science education. This is followed by the description of the analyzed variables and the outcome of the analysis. Finally, we will discuss the most important results and their implications in the CC field.

METHOD

Selection of the articles

We have chosen International ERIC Database as our main source of information. The search was limited to documents published in Journal or Review, during 1980-2001 interval, and we used the term Conceptual Change as Identifier, with Science Education as keyword. Thus we were able to identify 117 articles published in 20 different journals. It so happened that 4 influential journals covering the area of Science Education such as Science Education, International Journal of Science Education (formerly European Journal of Science Education), Journal of Research in Science Teaching and Research in Science Education, contained 78.5% of all the compiled information. We resorted to three criteria while making this second selection:

The article's topic had to deal with CC. By analyzing the article's title and its abstract we were able to identify the topic.

The article should include empirical results involving subjects, analysis of the results, interpretation as well as conclusions.

The research must have been carried out in the field of science teaching or learning, within a formal educational setting, at any education level, or under laboratory conditions.

This second search resulted in the selection of 59 articles that fulfilled the previously listed conditions (see Appendix).

RESULTS

Temporal distributions of research work

Figure 1 presents the distribution of articles during the studied period. It shows that research on CC has taken place in the last decade and that 49.2% of the articles were published in the last five years.

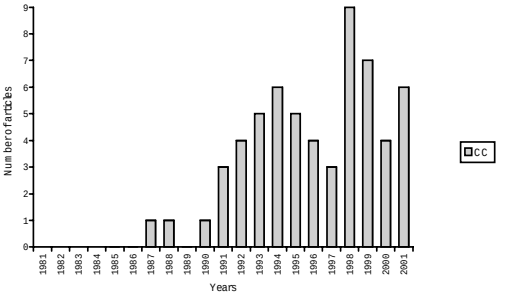

Figure 1. Distribution of articles on CC according to year of publication (source: ERIC database)

Research topics

Education level

Figure 2 shows research according to subjects' education level. The greatest part of research was done on subjects from high schools.

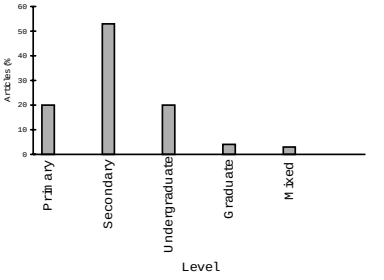

Figure 2. Distribution of articles according to educational level

Scientific topics

Different scientific topics have received unequal attention in research on

Conceptual Change (see Table 1). Conceptions in Physics were the most widely researched topics, especially those regarding Mechanics (22.0% of the total).

Physics	n	Chemistry	n	Biology	n	Others	n
Mechanics	13	Chemical equilibrium	2	Biological evolution	5	Science and religion	1
Electricity	6	Molecular interactions	2	Cardiovascular system	2	Mixed topics	7
Thermodynamics	4	Chemistry of solutions	2	Cellular respiration	2		
Light	3	Chemical reactions	1	Food chain	1		
Chaotic systems	1	Evaporation	1	Wetlands	1		
Astronomy	1	Acids and bases	1	Gene	1		
		Mole	1				
		Chemical bonding	1				

Table 1. Scientific topics and disciplines

Research areas

The articles were classified according to three main research areas after identifying the goals described by their authors. The first area, "Instructional strategies for CC" included articles whose goal consisted on evaluation of instructional strategies that influence some of the four conditions reserved for CC (Posner et. al. 1982). These studies examined the effectiveness of specific instructional strategies, such as cooperative learning or the use of computers for achieving CC goals. As it can be seen, this area has lost importance in recent years. Thus, fourteen of the 21 studies belong to the first half of the decade of the 90s, and only 7 appear in the second half of that period.

The second research area is "Students' conceptions and conceptual change". The purpose of these articles is to describe the evolution of students' alternative conceptions; they focus on such topics as energy, natural selection, or chemical equilibrium, and how the corresponding conceptions of students change. This area is closely related to the field of students' alternative conceptions. Nonetheless, the examined studies placed less emphasis on instructional strategies because their aim was not to propose tools for CC. Consequently; there is usually no reference to Posner's et. al. (1982) four conditions for CC. Fifty percent of the studies from this group have appeared during 1998-1999.

The third research area involved studies that focused on "Analysis and tests of CC models". These studies go beyond instructional efficiency or the characteristics of a particular student's conceptions, as in the previously cited research, and focus instead on the ontological, epistemological and metacognitive aspects of CC. They analyze key elements of CC such as the way the subjects' conceptions are restructured. It also involves studies on learning processes, conceptual ecology or the relative importance of the four cited conditions for CC. They summed up to a substantial part of the sampled articles (44.1% of all the studies), and its importance increased in the 90's, since 76.9% of these studies appeared between 1996 and 2000.

Table 2 shows how many studies belonged to each of the three areas.

Research Areas	n
Evaluating Instructional Strategies by means of Conceptual Change	
Cooperative learning	6
Use of computers	4
Use of analogies and mental models	6
Use of historical arguments	1
Use of writing	1
Use of refutational text	1
Use of conceptual substitution	1
Mixed language strategy	1
Students' Conceptions and Conceptual Change	
Physic targets	5
Chemistry targets	5
Biological targets	2
Analysis and test of CC models	
Nature and complexity of Conceptual Change	12
Metacognitive aspects	4
Ontological and epistemological issues	6
Conceptual ecology	2
Motivation issues	2

Table 2. Number of studies for each research type

Links with outside works

Table 3 shows the more frequently cited articles (those receiving 10 or more quotations). Posner et. al. (1982) appears as the main theoretical reference. Seventeen of 37 articles, who cited Posner et. al. (1982), used explicitly his model as the theoretical framework of their studies. In contrast, 67.8% of the sampled articles did not use any theoretical model to substantiate their studies. Although CC is mentioned in relation to intended students' learning, these studies were not based on any explicit CC model.

Article cited	% of articles citing
Posner, Strike, Hewson & Gertzog (1982)	62.7
Champagne, Gunstone & Klofer (1985)	28.8
Hewson & Thorley (1989)	23.7
Pintrich, Marx & Boyle (1993)	23.7
Strike & Posner (1992)	22.0
Osborne & Freyberg (1985)	18.6

Table 3. Most frequently cited articles

With respect to the most frequently cited authors (15 or more quotations), Driver received the bulk of quotations (cited in 62.7% of sampled articles), P. Hewson (40.0%) and Osborne (32.2%) came second and third, respectively. It should be pointed out that these quotations corresponded to articles' content, not necessarily dealing with CC topic. Also, the articles were authored by these researchers alone or together with other coauthors.

Methodological characteristics

The sampling was done on articles containing different methodological approaches, including experimental, quasi-experimental, and naturalistic methods. Several characteristics have been sought in all articles: sample's cohort size, duration, setting and type (quantitative vs. qualitative). In addition, internal and external validity have been appraised using different criteria for quantitative and qualitative studies.

Sample, duration, setting and type

With respect to sample, the studies ranged from 1 subject only (# 46 and # 57) to 310 (# 18). Social and cultural variables have not been explicitly considered in any of the studies. Duration of the study was also variable, from 20 minutes (# 16) to two school-years projects (# 57).

The most frequent setting for carrying out the studies was science lectures: 88.1% of the studies have been carried out within this scenario. Of course, such a complex setting makes it difficult to use experimental designs and to insure the internal validity of the quantitative studies. This issue is discussed farther on. The remaining 11.9% of the studies were done under more controlled, laboratory conditions.

With respect to the quantitative/qualitative ratio, there was higher percentage of qualitative studies, 55.9%, versus quantitative counterparts, 44.1%. The publishing frequency was also uneven: quantitative studies predominated during the first half of the 90's, while qualitative studies were published more often during the second half of the decade. See figure 3.

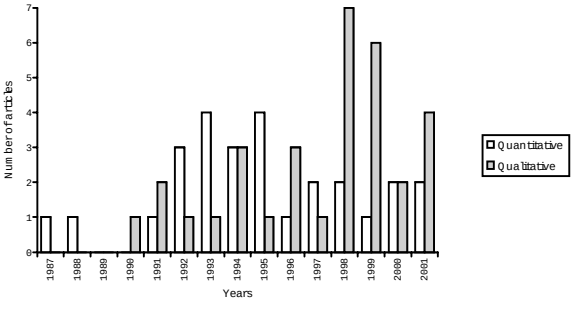

Figure 3. Temporal distribution of quantitative vs. qualitative articles

Internal and external validity

Internal validity in quantitative studies was appraised according to criteria based on Campbell and Stanley's (1963) classical study. In particular, we examined sampled articles while looking for 'the explicit mention in the text of the article' of: a) the existence of a control group, b) random assignment of subjects, c) existence of pretest and posttest, and d) other threats to internal validity. Among the latter we have included maturation, experi-

mental mortality, and testing. In view of the all above, internal validity was graded low, medium or high.

Credibility is a concept similar to internal validity when dealing with qualitative studies. Thus, credibility was appraised according to the criteria developed by Lincoln and Guba (1985). These include: a) persistent observation, i.e., the observer should stay in the field long enough to assure data's consistency, b) triangulation of observers , i.e., presence of two or more observers, and triangulation of measurements, i.e., using a variety of measuring methods, c) peers' critical judgment to reduce researcher's biases, d) use of reference materials, including documents, films and audio tapes that would allow analyses and reanalyses, e) verification of researchers' interpretations against the studied subjects.

Credibility judgments were made 'looking for explicit mention in the text of the article'. Persistent observation was always requested -for at least several days. Verifying through participants was discarded because of the difficulties to do this with children who participated in many studies. Consequently, credibility was scored depending on the number of observers and triangulation of measures. Secondly, when other threats existed such as lack of audiotape or video records, absence of explicit evaluation criteria for categorization or rating the subjects, and no-revision clues for supervision or replication of the methodological steps, credibility was decreased one degree.

Table 4 shows that 30.5% of the total number of studies had low internal validity or credibility. On the other hand, 30.7% of the quantitative studies attained high internal validity, and 39.4% of qualitative studies had high credibility.

Internal Validity/ Credibility Score	Quantitative (%)	Qualitative (%)	Total (quantitative + qualitative) (%)
High	30.7	39.4	35.6
Medium	38.6	30.3	33.9
Low	30.7	30.3	30.5
Totals	100.0	100.0	100.0

Table 4. Percentage of quantitative studies and qualitative studies according to internal validity score or credibility score

DISCUSSION

We were interested in getting answers to the three main questions posed at the beginning of this article. In continuation we shall deal with each one of them separately.

With respect to first question, we have found that international community interested in research on CC is composed of researchers from different countries and continents, mainly Australia, Europe and North America. But there is a clear dominance of USA researchers over Europeans and Australians.

Although the key papers on Conceptual Change were published at the beginning and halfway through the 80's, a substantial production of papers did not pick up until the decade of the 90's. This may be due to the fact that many researchers in science education were still working on the identification and description of misconceptions in science-an area that occupied much of research time on science education since the late 70's.

With respect to education level, the highest frequency of studies at the secondary level (high school) seems to reflect a research characteristic in the reviewed sample. The small number of studies at the tertiary level coincided with the general situation of science education studies concerning college students: traditionally less attention was paid to learning problems at this level as compared to the concerns of teaching adequate content.

Within this wide sample of studies we have noticed a predominance of topics on mechanics and biological evolution. The predominance of topics on mechanics may be partly explained by its immediacy, by its importance in Physics curricula, and by historical reasons: concepts in mechanics were the object of the first studies on students' alternative conceptions. Biological evolution forms an essential paradigm in Natural Sciences.

We have classified articles according to three areas of research. Articles in the first area "Instructional strategies for CC" were based on the assumption that instruction aimed at achieving CC should reflect the four conditions for change stated by the Cornell group in the 1982 paper. However Strike and Posner (1992) cautioned against a rigid translation of these ideas into instructional procedures.

The second area "Students' conceptions and conceptual change" represents continuity with the studies on misconceptions carried out in the past. The third area "Analysis and tests of CC models" gained importance in recent years as mentioned above.

Afterwards, we proceeded to analyze links within the sample and outside works to find out about the theoretical and empirical background of research on CC. Unsurprisingly, the article by Posner et. al. (1982) was the most widely cited in the sampled articles and constitutes the most important theoretical foundation for research on CC. Likewise, researchers belonging to Cornell Group produced several of the most frequently cited papers: Posner, Strike and Hewson , respectively authored two papers among the six of the most widely cited.

The ideas presented in the seminal paper by Posner et. al. (1982) were explained and extended in the 80's (Hewson, 1981; Strike & Posner, 1985; Hewson & Thorley, 1989) and later reformulated by Strike and Posner (1992). However, these additions and modifications were cited by less than 10% of the sampled articles. Since 74.6% of the articles in our sample were published after 1992, we concluded than researchers were not interested in these modifications. An alternative explanation for little impact of these later studies may be that they were not published in better-known journals. This assumption could be justified by the fact that another variant of the original ideas summed up in a paper by Hewson and Thorley (1989) originally published in International Journal of Science Education, is one of the six most frequently cited articles.

With respect to the methodological quality of research, we have found that only 30.7% of the quantitative studies had high internal validity, and only 39.4% of qualitative studies shared the same credibility. Threats to internal validity are associated with nonrandom convenience samples without a pretest, effects of instrumentation on the measured outcomes, and poor description of procedures should a replication were attempted. This last problem was especially true for qualitative studies.

There were frequent problems related to the validity of measuring instruments as well. Thus, in 31.0% of the quantitative studies we found an absence of explicit validation of the measuring instrument or/and scoring criteria. In 72.2% of qualitative studies there was an lack of criteria supporting a particular selection of information in students' cognitive structures, and/or explicit criteria for categorizing students' responses.

As previously shown, methodological approaches experienced a shift from predominantly quantitative to qualitative studies. However, the latter evidenced methodological problems too, basically related to the absence of precise safeguards such as triangulation, inter-judge agreement, and appropriate records for controlling and reducing researchers' biases.

CONCLUSIONS AND RECOMMENDATIONS

In retrospective, our review presents some hints suggesting that research on CC is still far from maturity. We have found serious deficiencies in the methodological aspect of that research, such as a lack of tradition in replicating previous studies, compounded by the high number of studies below desirable levels of validity.

Many of the points described in this review require the concurrence of the international community in order to establish, in a concerted way, the criteria and recommendations on which a progressive Research Program could be based, with agreed upon guidelines on the basic theory , the questions, the hypothesis, the methodological procedures and the plan of action for the research. An effort of this nature, as well as being important, would make a substantial advance possible in the research in this field and, at the same time, have a positive effect on the field of Science Education as a whole.

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IDENTIFICATION				METHODOLOGICAL CHARACTERISTICS					
Nº	AUTHOR(S)	YEAR	PUBLICATION	COUNTRY	LEVEL	SAMPLE	DURATION	SETTING	TYPE
1	Thorley & Treagust	1987	Int. J. Sci. Edu. 9(2), 203-216	Australia	Undergr	42	10 weeks	Natural	Quantitative
2	Rogan	1988	Sci. Edu. 72(1), 103-113	USA	Seconda	145	14 sessions	Natural	Quantitative
3	Dreyfus et al	1990	Sci. Edu. 74(5), 555-569	ISRAEL	Seconda	48	Not stated	Clinical	Qualitative
4	Trumper, R.	1991	Int. J. Sci. Edu. 13(1), 1-10	ISRAEL	Seconda	35	Not stated	Natural	Qualitative
5	Basili & Sanford	1991	J. Res. Sci. Teach 28 (4), 293-304	USA	Undergr	62	6 periods	Natural	Quantitative
6	Fleer & Beasley	1991	Res. Sci. Educ. 21, 104-112	Australia	Primary	24	6 months	Natural	Qualitative
7	Jiménez-Aleixandre	1992	Int. J. Sci, Edu. 14(1), 51-61	SPAIN	Seconda	69	2 weeks	Natural	Quantitative
8	Brown	1992	J. Res. Sci. Teach. 29(1), 17-34	USA	Seconda	21	45 min/stud.	Clinical	Quantitative
9	Gunstone et al	1992	Sci. Edu. 76(2), 175-197	Australia	Seconda	28	4 weeks	Natural	Qualitative
10	Fetherstonhaugh et al	1992	Sci. Edu. 76(6), 653-672	Australia	Seconda	20	3 weeks	Natural	Quantitative
11	Hameed et al	1993	Int. J. Sci. Edu. 15(2), 221-230	Australia	Seconda	30	2 sessions	Natural	Quantitative
12	Rollnick et al	1993	Int. J. Sci. Edu. 15(4), 363-381	South-Africa	Graduat	145	2 weeks	Natural	Quantitative
13	Lawson et al	1993	J. Res. Sci. Teach 30(9), 1073-85	USA	Undergr	77	6 sessions	Natural	Quantitative
14	Lonning	1993	J. Res. Sci. Teach 30(9),1087-1101	USA	Seconda	36	4 weeks	Natural	Quantitative
15	Tytler	1993	Res. Sci. Edu. 23, 308-316	Australia	Primary	113	2 sessions	Natural	Qualitative
16	Brown	1994	Int. J. Sci. Edu. 16(2), 201-214	USA	Seconda	73	20 min/stud.	Clinical	Quantitative
17	Songer & Mintzes	1994	J. Res. Sci. Teach 31(6), 621-637	USA	Undergr	200	4 sessions	Natural	Quantitative
18	Hynd et al	1994	J. Res. Sci. Teach 31(9), 933-946	USA	Seconda	310	sessions	Natural	Quantitative
19	Fellows	1994	J. Res. Sci. Teach 31(9), 985-1001	USA	Primary	25	12 weeks	Natural	Qualitative
20	Grayson	1994	Res. Sci. Edu. 24, 102-111	South-Africa	Undergr	67	2 years	Natural	Qualitative
21	Hulland & Munby	1994	Sci. Edu. 78(2), 117-136	Canada	Primary	2	2 weeks	Natural	Qualitative
22	Hennessy et al	1995	Int. J. Sci. Edu. 17(2), 189-206	UK	Seconda	29	7 weeks	Natural	Quantitative
23	Demastes et al	1995	J. Res. Sci. Teach. 32(5), 535-550	USA	Undergr	192	1 week	Natural	Quantitative
					Seconda	180	6 weeks	Natural	Quantitative
24	Ebenezer & Gaskell	1995	Sci. Edu. 79(1), 1-17	Canada	Seconda	13	8 sessions	Natural	Qualitative
25	Jensen & Finley	1995	Sci. Edu. 79(2), 147-166	USA	Undergr	42	10 weeks	Natural	Quantitative
26	Demastes et al	1995	Sci. Edu. 79(6), 637-666	USA	Seconda	4	17 sessions	Clinical	Qualitative
27	Treagust et al	1996	Int. J. Sci. Edu. 18(2), 213-229	Austr-USA	Seconda	39	20 min/stud	Clinical	Quantitative
28	Lee & Brophy	1996	J. Res. Sci. Teach. 33(3), 303-318	USA	Primary	2	12 weeks	Natural	Qualitative
29	Demastes et al	1996	J. Res. Sci. Teach. 33(4), 407-431	USA	Seconda	3	1 year	Natural	Qualitative
30	Arnold & Millar	1996	Sci, Edu. 80(3), 249-281	UK	Seconda	94	6 weeks	Natural	Qualitative
31	Chambers & Andre	1997	J. Res. Sci. Teach. 34(2), 107-123	USA	Undergr	206	3 days	Natural	Quantitative
32	Thorley & Woods	1997	Int. J. Sci. Edu. 19(2), 229-245	USA	Primary	3	2 classes	Natural	Qualitative
33	Pearsall et al	1997	Sci. Edu. 81. 193-215	USA	Undergr	161	1 semester	Natural	Quantitative
34	Stavridou et al	1998	Int. J. Sci. Edu 20(2), 205-221	Greece	Seconda	40	Not stated	Clinical	Qualitative
35	Van Driel et al	1998	Int. J. Sci. Edu 20(4), 379-392	Netherland	Seconda	241	3 cycles	Natural	Qualitative
36	Tytler	1998	Int. J. Sci. Edu 20(8), 929-958	Australia	Primary	---	3 times	Natural	Qualitative
37	Roschelle	1998	Int. J. Sci. Edu 20(9), 1025-1042	USA	Seconda	2	1 sessions	Clinical	Qualitative
38	Duit et al	1998	Int. J. Sci. Edu 20(9), 1059-1073	Germ-Cana	Seconda	5	1 sessions	Natural	Qualitative
39	Windschitl & Andre	1998	J. Res. Sci. Teach. 35(2), 145-160	USA	Undergr	250	3 weeks	Natural	Quantitative
40	Venville & Treagust	1998	J. Res. Sci. Teach. 35 (9), 1031-55	Australia	Seconda	29	10 weeks	Natural	Qualitative
41	Wilson	1998	Res. Sci. Edu. 28(4), 429-446	Australia	Mix:s-u	144	1 sessions	Natural	Quantitative
42	Beeth	1998	Sci. Edu. 82, 343-356	USA	Primary	12	9 months	Natural	Qualitative
43	Tao & Gunstone	1999a	Int. J. Sci. Edu. 21(1), 39-57	China-Aust	Seconda	14	10 weeks	Natural	Qualitative
44	Shepardson & Moje	1999	Int. J. Sci. Edu. 21(1), 77-94	USA	Primary	4	15 hours	Natural	Qualitative
45	Case & Fraser	1999	Int. J. Sci. Edu. 21(12), 1237-1249	South-Africa	Undergr	81	Not stated	Natural	Quantitative
46	Harrison et al	1999	J. Res. Sci. Teach. 36(1) 55-87	Australia	Seconda	1	8 weeks	Natural	Qualitative
47	Stahly et al	1999	J. Res. Sci. Teach. 36(2) 159-177	USA	Primary	12	3 weeks	Natural	Qualitative
48	Tao & Gunstone	1999b	J. Res. Sci. Teach. 36(7) 859-882	China-Aust	Seconda	27	10 weeks	Natural	Qualitative
49	Thomas	1999	Res. Sci. Edu. 29(1), 89-109	Australia	Primary	3	8 weeks	Natural	Qualitative
50	Tytler	2000	Int. J. Sci. Edu. 22(5), 447-467	Australia	Primary	302	Not stated	Natural	Qualitative
51	Sanger & Greenbowe	2000	Int. J. Sci. Edu. 22(5), 521-537	USA	Undergr	135	Not stated	Natural	Quantitative
52	Know & Lawson	2000	J. Res. Sci. Teach. 37(1), 44-62	Korea-USA	Seconda	210	2 hour total	Natural	Quantitative
53	Loving & Foster	2000	Sci. Edu. 84, 445-468	USA	Graduate	9	5 weeks	Natural	Qualitative
54	Windschitl	2001	Int. J. Sci. Edu. 23(1), 17-32	USA	Seconda	90	2 weeks	Natural	Quantitative
55	Lee & Law	2001	Int. J. Sci. Edu. 23(2), 111-149	China	Seconda	6	-----	Clinical	Qualitative
56	Reiner	2001	Int. J. Sci. Edu. 23(6), 551-568	Israel	Seconda	28	24 sessions	Natural	Qualitative
57	Taber	2001	Int. J. Sci. Edu. 23(7), 731-753	UK	Undergr	1	two years	Natural	Qualitative
58	Thomas	2001	J. Res. Sci. Teach. 38 (2), 222-259	China-Aust	Seconda	24	18 months	Natural	Qualitative
59	Nieswandt	2001	Sci. Edu. 85, 158-179	USA	Seconda	81	one year	Natural	Quantitative

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