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Curriculum development for technology education : a perspective from Colombia

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Abstract
A new law of education, passed in 1994 (Law 115/95), established technology and informatics as one of the nine compulsory curricular subjects for basic and secondary education in Colombia. Proposals for the new area were urgently needed, but curricular development in Technology Education (TE) has proven not to be an easy task. The present paper describes the foundations of a curricular structure developed jointly by the Master's Programme in Pedagogy of Technology (National Pedagogical University), and DifuCiencia, a NGO working in Science and Technology (S&T) literacy programs. This is the first outcome of a joint Research and Development(R&D) project sponsored by Bogotá's Secretary of Education, which has included on-the-job training for almost 600 public school teachers in Colombia's capital.

The starting point is an epistemological delimitation of technology. Technological knowledge is conceived as having two main foundations: Mechanical logic and strategic thinking. Mechanical logic is that knowledge accumulated through the historical development of technology, from stone-age instruments to contemporary digital machines. Another important part of technological knowledge is practical problem-solving; however, not all strategic thinking is related to mechanical logic or to technology.

A curricular structure for TE can, then, be defined based on three main axes: a) Stages of historical development of technology; b) Learner's stages of cognitive development; and, c) The concept of 'learning environments' didactic principle. Further learning activities and the precision of an initial proposal of competencies and their related attainment targets are matters of research involving public school teachers in Bogotá.

A necessary delimitation

A new law of education, passed in 1994 (Law No 115/'94), established *technology and informatics* as one of the nine compulsory curricular areas for basic and secondary education in Colombia. Thus the need for developing curricular proposals for this new subject became evident. However, this endeavour proved to be all but easy. On the one hand, basic and secondary education teachers lack experience with the pedagogy of technology. On the other, given the high complexity of contemporary technology, an epistemological delimitation of technology, a necessary task for technology education (TE), becomes a complicated matter.

It seems a good criterion for developing this delimitation to understand technology as that set of activities leading to the production of the artificial environments which a large part of mankind inhabit. However, these environments, in becoming so highly sophisticated pose a dilemma : as they become more transparent to the user, they demand higher-level intellectual capacities both for technological literacy and for innovation.

Such a dilemma implies complex educational challenges, among which the two most important, perhaps, are the following. Firstly, contents that not so long ago were the matter of higher education for engineers must become part of basic and secondary education for all, so that engineering education can meet the increasingly higher levels of abstract thought demanded by today's complex technological systems.

Secondly, since *project* and *design* are basic activities of contemporary technology, it seems rather natural to conclude that all students must do is to master the *design method* and/ or the *project method*. Unfortunately, things are not so simple. Education for 'creativity' or developing capacity for innovation cannot be reduced to the mere learning of a 'methodology' or, what seems tantamount to a *procedure*.[1]

In our work, we are increasingly confronted with the fact that educating a creative individual requires also domain-based knowledge. This seems related to what Novak has termed 'supraordinated knowledge', which he considers closely linked to creative behaviour.[2] In our terminology, we feel that there exists 'cognitive conditions' for creativity.

The inescapable conclusion is that TE requires a domain-based, that is, a *technological* knowledge.[3] This is why an epistemological delimitation of technology is necessary for planning TE.

The present paper describes the **theoretical propositions** behind a curricular structure developed jointly by the Master's Programme in Pedagogy of Technology of the National Pedagogical University of Colombia, and DifuCiencia, a NGO working in S&T literacy programs. This is the preliminary result of a joint R&D project between these two entities, partially sponsored by Bogotà's Secretary of Education and which has also included on-the-job training of almost 600 public school teachers in the Colombian capital.

Previous definitions : technology and technological knowledge

The design of a curricular structure for TE demands, as discussed earlier in this paper, an epistemological outline, firstly, of that confine of human experience in which that set of activities we call *technology* has developed and, secondly, of the **nature** of the knowledge that has been built in that context.

The social confine of technology

The actions of work, as the production of the material conditions for human living, conforms the extent of social experience in which technics and technology have evolved. We find in this context man's activities in transforming nature, activities that have finally concluded in the artificial environments in which large percentages of mankind live. It is evident that those actions have also changed man's needs through history, from the caves to contemporary society.

In this outline of technology we shall refer only to the production of material goods, i.e., to **action as work**. It is not necessary to take into account how men relate to each other in this process.[4] Understanding technology in all its complexity means considering it as an **active process**. In other words, in order to examine the nature of technology it is necessary to start with the productive cycle that generates material goods.[5]

Even though the conditions of that cycle have changed through history, it is possible to identify four major invariants, present in every productive cycle. These are: **Purpose**, objective, goal; **Means**, conformed by the raw materials to be transformed, tools machines and other equipment used in the transformation, and a power supply; **Processes**, methods and ways of organising labour division in order to achieve the purpose; and, **Product**, good or commodity.

The development of these four factors in order to make them more productive, a constant pursuit in almost every human culture, is the essence of technics and technology.[6] The presence of technology in these four invariants could be considered as follows:

- In the purpose: as design and planning strategies.
- In the means: as research and development of new materials, instruments, tools or machines.
- In the processes: as developments in the methods and ways of organising the labour division for production.
- In the product: as improvements in the quality of the final good. Here, the cycle, that feeds permanently back in its development, closes itself in a materialised purpose.[7]

Technology, in a final stance, represents a mimicry of the operational functioning of human beings and of nature's processes. In this respect, Habermas notes:

> "The evolution of technics/technology may be adjusted to the following interpretative model: (...) first, the functions of the locomotive apparatus (hands and legs) are substituted; later, the energy supply (by the human body); later on, the functions of the senses (eyes, ears, skin) and, finally, the functions of the control centre (brain)".[8]

As stated before, starting to understand technology requires examining the productive cycle of material goods. Something different is the impact of the use of high-tech goods such as happens in today's transportation and communication systems, a phenomenon that is frequently mistaken as technology.

The productive cycle has gone through different levels in different historical circumstances. Understanding contemporary technology requires comprehension of the conditions of the most developed cycle and its influence in less developed societies.

The most developed cycle, which can be found in the USA, Western Europe and Japan, has emphasised the development of certain aspects such as:

- Preferential orientation of design to innovation in consumer goods, rather than in the means of production.[9] Innovation in consumer goods consist mainly in formal modifications.
- Importance granted to innovations in the processes and ways of organising production, an aspect of technology known as 'problem-solving'.[10]
- Intensive use of information at the expense of a relative reduction in the use of energy and raw materials.[11]
- Software development for flexible manufacturing systems and innovations in organisation and methods.[12]

This emphases of the highly developed cycle, along with the raising of illusive necessities, typical of the consumer's society, has generated a perception that technology is intangible and has fostered the idea that it is based only in creativity and strategic capacities, not demanding any knowledge domain. The influence of these misconceptions, that have intended to reduce **all** technological knowledge to its formal and symbolic aspects[13] in TE is another important reason for this epistemological delimitation.

The nature of technological knowledge

The actions intended to achieve a goal or purpose, that is, of work may be understood in two ways: either as instrumental action, or as strategic action.[14] Both, instrumental and strategic actions, are operational in the sense that they are actions oriented to choose among alternatives, which implies prediction, calculation, regulation, control and the search for efficiency in a productive process or in the use of a product of technology.

Those actions of men in transforming nature and producing goods are oriented by peculiar ways of thinking, that have been characterised as *instrumental* and *strategic* reasons or logics.[15] Instrumental reason materialised in the development of machines throughout history has become **mechanical logic**. This mechanical logic, of course, implies strategic thinking also, but there are instances of strategic thinking not limited to mechanical logic, such as certain organisational processes and the mimicry of nature's processes in biotechnology.

Accordingly, mechanical logic and strategic thinking would be the components/ foundations of the operational principle, proposed by Polanyi[16] as the central category of technological knowledge.

Mechanical logic has evolved, along the course of human history, resulting in an increasing accumulation of technological knowledge and the development of mechanical operators systematised in a theory of machines. More recently, since Norbert Wiener's theoretical models, **logic** operators have become part of this knowledge. The development of mechanical logic is universal in the sense that it takes on a character of **necessity** in different human cultures.[17]

As to the different expressions of strategic thinking, these have been more conditioned by historical and cultural variants. It is possible to forecast that there would be many developments in strategic logic, not necessarily related to mechanical logic.

Finally, this effort to delimitate technological knowledge, a necessary, prior conceptualising to developing a curricular structure for TE, does not mean ignoring other related knowledge, particularly that from natural sciences. It is considered appropriate that, in higher educational grades/levels, concepts from social sciences, in general more abstract than those of natural sciences, should be taken as a basis to reflect on the social and ethical impact of technology and its applications.

Structural elements of the curricular proposal

Historic development of technology

Several authors (eg Piaget, Habermas) have noted a parallel between the large stages of mankind's history and those of the cognitive development of the individual. This parallel suggest that one of the axis for a curricular structure would be given by the stages of historic development of technology, from the initial stone-age instruments to current-day robots.

Thus, historical development of mechanical logic - from its beginnings in the shape of an instrument reflecting the purpose behind it, to the logic operators of today's digital machines - furnishes a guide to design a sequence of technological knowledge contents along the different levels of basic and secondary education.

Students' stages of cognitive development

An evident and important element for defining a curricular structure should be how it fits the levels or degrees of cognitive development of the learners involved. In this case, Piaget's theory allows preliminary definitions of curriculum stages and attainment targets.

The possibilities for competent performance or for being part of decision-making that somebody may have, are closely related to his/her comprehension of contemporary artificial environments. This understanding requires, as we have seen, the development of capacities for abstract thinking.

Accordingly, the curricular structure is based on the necessities of intellectual development if the students are to understand contemporary technology. Other needs, such as those of the local environment, the pressing income needs of socio-economically deprived sectors, should only be considered in the particular level of curricular implementation, that is, at the didactic level.

The concept of 'learning environment' as 'didactic principle'

In addition to key concepts (such as 'system', 'design', 'structure', 'function', etc.), technological knowledge also includes a strong factor which differentiates it from other types of knowledge, particularly from scientific knowledge. Exercising these two aspects, conceptual and practical, implies to foster in the students the development of the capacity for strategic thinking along with the understanding of the foundations of mechanical logic. This could be possible by means of strengthening students' ability for practical problem-solving in a series of classroom activities duly organised as 'learning environment'.[18]

Items of the proposal

Curricular structure includes:

1 School levels and the corresponding average ages, grouped according to the stages of cognitive development as proposed by Piaget.

2 Technological knowledge contents. That is, the contents of mechanical logic as constructed through action and operativity, arranged sequentially according to the large historic stages of technology development. Four major stages are considered: A.- The Instrument; B.- The Instrument + Mechanical operators; C.- The Instrument + Mechanical operators + Power supply; D.- The Instrument + Mechanical operator + Power supply + Regulation and Control.

3 Suggested classroom activities, as a guide for further designing 'learning environments'. A certain number of these activities have been developed by DifuCiencia's staff and students of the Master's programme. They are being validated in schools by teachers participating in an on-the job training program financed by Bogotá's Secretary of Education.

4 Competencies. Includes definition of the capacities related to apprehension of mechanical logic and the development of strategic thinking, in relation to the stages of cognitive development.
Two precisions are necessary at this point. First, 'competency' is a domain-based capacity associated with the possibility of applying knowledge in different contexts. Second, the competencies presented in the curricular structure correspond to the proposal discussed in the work about 'learning environments' with some variations dictated by practice.[19]
It was necessary to itemise two of the original competencies in items both readily measurable and that gave indication as to the educational ways of promoting it as a competency. Thus, the capacity for structuring and formulating problems ended up divided into two: i.- Capacity for representing objects, artifacts and situations using different languages, particularly those associated with technology, such as descriptive geometry and mathematics. ii.- Capacity for establishing differentiations, classifications, analogies and variables related to mechanical logic. The capacity for developing and presenting proposals of solutions was also divided into two: i.- Capacity for discriminating among several alternatives, and, ii.- Capacity for explaining the reasons for decision-making.
Finally, the tendency to self-control one's own formative process was suppressed because it is not really a 'competency', rather a degree of maturity as a result, expectedly, of the other four.

5 Attainment targets. A definition of the levels of acceptability of several indicators related to the competencies. The idea is that a learning objective is an attainment target at the youngest age in which such learning is possible but means a cognitive challenge for the learner. The initial proposal is inspired by Piaget's theory, but a final precision of every indicator depends on experimental work, already underway, directed by DifuCiencia with the participation of groups of teachers in Bogotá's public education system.

6 Some related knowledge, particularly of the natural sciences, corresponding to the contents of technological knowledge.

Notes

1 Experimental evidence and a critique of the outcomes of this 'procedural' approach to TE may be seen in McCormick, R., et al. (1994) 'Problem-solving processes in technology education : a pilot study '. *International journal of technology and design education*, 1 , 4, Kluwer Academic Publishers. See also Andrade, E. (1995) 'Teoría y práctica de la educación en tecnología' (Theory and practice of TE). *Educación y cultura*. Revista del CEID-FECODE, Bogotá, 36-37, and McCormick, R. et al. (1997) 'Diseño y tecnología como revelación y ritual' (Design and technology as revelation and ritual) *Revista eduación en tecnología*, Bogotá, 2, 2.

2 In Novak's terms, 'supraordinate knowledge' involves meaningful learning of highly abstract concepts. This would allow a creative individual to establish relationships among lower-level concepts that others are not able to 'see' by themselves. Cfr. Novak, J. (1997), *A theory of education*, Cornell University Press. We used the Spanish translation by Alianza Editores, Madrid, 1982.

3 At a more basic level, not only creativity but intelligence itself, when considered a faculty that can be developed rather than a birth-gift, requires also a domain-based knowledge. See, for example, the discussion about Piaget's conception of intelligence in Legendre-Bergeron, Marie-Francoise (1994) 'Une conception dynamique de l'inteligence' (A dynamic conception of intelligence) *Vie Pedagogique*, MAY-JUNE, Québec.

4 This limitation is necessary in order to leave social relations out of the realm of *technology*. Taking these social relations into account is entering into the realms of history, political economics and/or sociology.

5 This stance is quite different from that which attempts to comprehend technology

by means of 'object analysis', i.e., considering isolated goods. This object analysis may be valid as a method for reconstructing the design process of that particular commodity. But technology is not only design.

6 *Technics*, strictu sensu, refers to the instruments and processes involved in shaping materials, whereas *technology* implies both the reflection (logos) about those instruments and processes, as well as the coordination of several technics in order to achieve a production goal.

7 "In Bachelard's view, design is an epistemological region where the theoretical becomes matter. Design is a sort of operator that transforms abstraction into concrete objects". Perez, U. (1997) 'Aspectos contextuales del trabajo educativo en el ámbito del conocimiento tecnológico'. (Contextual aspects of educational labour in the realm of technological knowledge). *Memorias (Proceedings) 1st Colombian and Latin American Congress of TE,* EDenTec'96. Bogotá, 28.

8 Habermas, Jurgën. (1992), *Ciencia y técnica como* '*ideología*' (Science and technics as 'ideology',1968) Editorial Tecnos, Madrid, 61-62.

9 See Lotero-Botero, Amparo. (1997) 'Los significados cambiantes'. (Changing meanings) *Educación en tecnología*, Bogotá, 2, 2,17-30.

10 "The general and complex organisation of the enterprise is a manifestation of advanced technology, perhaps more tangible then machinery itself. (...) The task of problem-solving (...) is an already identified treat of modern technology". Galbraith, J. K. (1984), *El nuevo estado industrial* ,(The new industrial state, 1967) Editorial Sarpe, Madrid, 65.

11 "... Japan increased her industrial production by two and a half times, almost without increasing her consumption of raw materials and energy. (...) The newest 'energy' of all, information, has contents neither of matter nor energy. It is completely knowledge-intensive". Drucker, P. (1990) *Las Nuevas Realidades* (The new realities), Editorial Norma, Bogotá, 117.

12 "The use of knowledge, in full activity since the 70s, consisted in applying system analysis to the production process itself. Here, the hardware is not essential (...)". Drucker, P. (*op.cit.,* p 181)

13 "{The new knowledge statute} has been widely elaborated by experts and is already directing certain decision-making in public administration and in the private corporations most involved, like those of telecommunications. It is already part of the order of perceived realities". Lyotard, J.F. (1994), *La condición post-moderna* (The post-modern condition, 1984) Ediciones Cátedra, Madrid, 21.

14 Habermas, J. (*op.cit.,* p. 68)

15 Habermas, J. (*op.cit.,* p. 106)

16 Quoted in Layton, David (1993), *Technology's challenge to science education*. Open University Press, Buckingham, 48-49.

17 "This law enunciates an intra-technical event, a development not sought by men, but something that has imposed itself on men along all history of human culture. In addition, according to this law, there cannot be any technical development beyond complete automation, since it would not be possible to specify any other realm of functional human activity that could be substituted". Gehlen, A.(1965) *Antropoligische ansicht der technik*, quoted in Habermas, J. (*op.cit.,* p. 62)

18 A wider discussion on the idea of transforming the classroom into a 'learning environment' can be found in Andrade-Londoño, E. (1996) 'Ambientes de aprendizaje para la educación en tecnología' (Learning environments for TE). *Educación en tecnología*, 1, 1, Bogotá, 1-15. An English version was

presented at JISTEC'96. See Book of Abstracts, Jerusalem, Jan 8-11/96.

19 Cfr. Andrade-Londoño, E. (*op.cit.*) The original proposal in this paper consisted of 5 competencies derived from the idea that TE should form: a- Technologically literate citizens; b.- Technology innovators. These competencies are: 1.- Ability to use information sources; 2.- Capacity for structuring and formulating problems; 3.- Capacity for developing and presenting proposals of solutions; 4.- Some technical skills; 5.- Tendency to self-control one's own formative process.

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Appendix

SCHOOL LEVELS (AVG.AGES)	TECHNOLOGICAL KNOWLEDGE (OPERATIONAL)	SUGGESTED ACTIVITIES	COMPETENCIES	ATTAINMENT TARGETS	RELATED KNOWLEDGE
0- 1o (4-7 years) =>Pre-operational<=	Shaping materials	Handling materials (dow, ceramics,..) for making familiar objects.	Fine motricity. Eye-hand coordination.	Relates the shape of an object with its function.	
2o-3o (7 - 9 years) =>Concrete operations<=	Shaping materials with an intended purpose	Clasifying materials; game of cards: sequence of various production processes; Exploring household appliances & moving toys.	¡ Establishing differentiations, classifications, analogies & variables refered to artificial environments. ¡ Skills	Differentiates purpose- material- tool-process. Uses tools with an intended purpose.	
3o-4o (10 - 11 years) =>Concrete operations<=	Simple structures. Simple machines. Transmission of motion.	Building simple structures. Playing with mechanisms. Where to find mechanisms in a real context. Using Papus "minicomputer" as introduction to binary system.	¡Using information sources ¡ Representing objects, artifacts, situations. ¡Establishing differentiations, classif., analogies & variables refered to artificial environments. ¡Discriminating among alternatives ¡Explaining decision-making. ¡ Skills	Follows written instructions. Understand 2-d drawings of 3-d objects. Represents 3-d objects in 2-d drawings. Differentiates the part from the whole, and understands the whole as organization of parts. Solves problems using mechanisms. Free-hand sketching.	Principles of pulleys, levers, wedges. Binary system
5o -6o (7o) (11 - 13 years) =>Transition to Formal operations<=	Changing the plane of rotational axis. Speed/power relations. Transforming linear motion into rotational motion. Energy supplies. Motors (comb. & electr). Simple electrical circuits.	Solving functional problems using mechanisms & mathematical expressions Simple experiments about cycles in living beings. Building simple motors.	¡Using information sources ¡ Representing objects, artifacts, situations. ¡Establishing differentiations, classif., analogies & variables refered to ... ¡Discriminating among alternatives ¡Explaining decision-making. ¡Skills	Reads catalogs. Represents operational relations using formal operators. Differentiates natural environments form artificial environments. Solves mechanical logic problems using simulators and formal operators. Uses some machine-tools safely & purposefully.	Concepts of Force & Work. Life reproduction cycles. The paths of energy. Energy in natural & artifical environmnts. 1a & 2a Laws of thermodynamics.

Proposed curriculum structure for Technology Education in Colombian schools (continues on next page)

SCHOOL LEVELS (AVG.AGES)	TECHNOLOGICAL KNOWLEDGE (OPERATIONAL)	SUGGESTED ACTIVITIES	COMPETENCIES	ATTAINMENT TARGETS	RELATED KNOWLEDGE
(7o) 8o-9o (<13 years) =>Formal operations<=	Complex, articulated strucutures. Agricultural systems. Generating useful energy Regulation & control. Logical representation of the machine as a system. Introduction to linear programming & formal operators. Introduc.to automation & robotics.	Building articulated structures. "Minicomputer" & punched cards for binary system. Introduction to analog & digital electronics. Principles of linear programming. Using information sources and designing a Wall S&T Journal.	¡Using information sources ¡ Representing objects, artifacts, situations. ¡Establishing differentiations, classif., analogies & variables refered to artificial environments. ¡Discriminating among alternatives ¡Explaining decision-making. ¡Skills	Uses updated information on recent technological developments. Represents situations using formal operators. Establishes variables in different artificial environments. Differentiates means of production from final good. Differentiates artifact from object. Develops proposals for progmm. mechanical systems. Uses software purposefully	Binary system Probabilities. Concepts of information, & system. Geometry & Descriptive geom. (orthogonal projection). Concepts of ecology. Thinking about technology and environment.
10o -11o =>Formal operations<= High- level abstractions	Understanding contemporary world of labor. Using technologies in different contexts. (Telecommuni.; Automat. & robotics;Biotechnology; Food technology; Networking & informatics; Managerial strategies)	Formulating problems. Designing solutions. Design drills in different task environments.	¡Using information sources ¡Representing obj., artifac.,situations ¡Establishing differentiations, classif., analogies & variables refered to ... ¡Discriminating among alternatives ¡Explaining decision-making. ¡Skills	Uses historical & updated information in homeworks. Develops & builds prototypes in different task environments. States arguments & strategies by writing. Uses tools, machine-tools, measuring & other equipment safely & adequately.	Math. related to linear programm., electronic circuitry & fluid mechanics. Introd. to quantum mechanics, relativity, genetics, biochem. Reflexions about society-ethics - technology.