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EDUCATING A WORKFORCE FOR ARTIFICIAL INTELLIGENCE AND ROBOTICS IN CONSTRUCTION

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ABSTRACT

Artificial intelligence and robotics will change construction practices and education sufficiently to require new approaches, starting with design and continuing into facilities management. Current linear relationships of the parties to construction shall change to become clustered relationships, to allow better integration of services. Clustered relationships will cause owners, designers, constructors and managers to pool their knowledge to plan, build and operate buildings with maximum efficiency and economy. Robots will be used not only to build buildings but also to maintain them. Skilled workers will be dichotomized between primary, who actually perform construction, and secondary, who maintain the sophisticated equipment which does most of the work. Education is reviewed from a constructivist point of view, and models are offered as guides for strategies for adapting education to a rapidly changing technical environment.

INTRODUCTION

If we accept the thesis that artificial intelligence and robotics are to become salient operational aspects of construction, then we must re-examine the education and training that support construction. We should not, however, dwell on construction as isolated from the rest of commerce and industry, because as those activities continue to move rapidly to automation, it is logical that construction will follow, lagging somewhat behind, but necessarily adapting more closely to manufacturing and marketing practices.

It seems, therefore, necessary to take a whole view of education, how we got to our present condition and the forces which are pushing for change. Important among those forces is, of course, the worldwide technological movement that includes robotics. This discussion will dwell principally on the United States of America, with references to the European tradition and global economic forces.

Within the whole view, attention is given to a historical perspective and to learning theory prior to primary focus on the education and training relevant to design, construction and facilities management. Currently these are three separate functions with four approaches to educational preparation. Linear relationships have developed in which responsibilities are fragmented, and insufficient cohesion is afforded to the overall design/construct/maintain continuum:

Fig. 1 Linear Relationships

Robotics will cause different concepts of buildings, not just in how they are built, but how they are owned, used, maintained and recycled. For example, as manufacturing faces quick changes in a volatile marketplace, it may not be practical for manufacturers to own large capital assets. Rather, new style companies may design, build, own, maintain and lease production space. Even robots themselves may be leased for particular manufacturing processes. In any regard, the linear relationships referenced above should yield to clustered relationships in which the activities become more closely related — so that designers know more about how buildings are built, maintained and recycled; constructors and facility managers know more about design; and all know more about robotics.

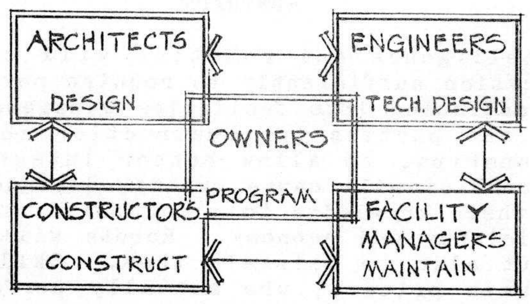

Fig. 2 Clustered Relationships

What implications do clustered relationships hold for construction education and training? The key words become economy and integration. In a competitive world marketplace, buildings must be economical on a life cycle basis, and to achieve these objectives integration of design, construction and maintenance activities are necessary. The practitioners of these services need to learn how to work more closely together. Adversarial relationships must be reduced. It all begins in education— and as early as possible.

HISTORICAL PERSPECTIVE

Education vs. training is an historic tension. There has always been conflict between formal general education and special applied training. This has caused an ongoing twin focus on a society's needs for a responsible and productive citizenry. The traditional view is that a liberal knowledge of arts and sciences provides the basis of the development of the whole person and the framework for a career of leadership in public life. In most nations such education was aimed at a privileged few who were somehow predesignated for special roles. The greater masses were then directed to a hierarchy of skilled and unskilled positions.

Skill training has traditionally been dichotomized between structured long-assimilation processes (as characterized by guild and apprenticeship programs) and directly applied experiential training. People not accepted into special training programs had no alternative but to learn through experience on the job. Thus three modes of learning have endured:

Formal education
Special training
On-the-job experience

The separation of formal, special and on-the-job remains strong in the European tradition. Youths are still selected out in early adolescence for particular educational tracks. In the United States, However, both the democratic ideal and the need for a large number of literate workers caused a merging of the three. Some level of formal education was necessary to be able to fulfill the duties of citizenship, and there was need for a moderately trained workforce to power the burgeoning industrial revolution.

Thus the unique concept of educating everyone to the limit of his or her possibility gradually took place in the U.S.; gradually because the dream did not approach reality until the mid-twentieth century. After World War II, heightened importance was placed on education as the U.S. reluctantly moved into global leadership. It was clear that the maturing industrial/scientific age would require more well educated people. College enrollments swelled with returning military servicemen, plus young secondary school graduates eager for better employment than their parents had had.

At the same time, vocational training was gaining momentum as an alternative form of education for those secondary students not choosing to pursue higher education. The perceived model, not unlike those in Europe, was that half of the students should be prepared for further education and half should be prepared for direct employment at age eighteen out of secondary school. However, this 50/50 model never took hold because most parents dreamed of sending their children to higher education. Thus a multi-billion dollar network of vocational schools was built but never used to full potential.

On-the-job experience remained valid in the U.S., but most employers expected the public education system, supported by their tax dollars, to prepare job entrants with the basic skills necessary to augment quick applied learning. Employers have generally favored quick adaptation programs rather than extensive apprenticeship type training.

LEARNING THEORY

There has been much recent exploration of learning theory. In history's most turbulent century, everything has come into question, particularly education, which is seen as the pathway to national security, democratic equality and a whole host of other goals. So, the fundamental question continues to be asked: How do people actually learn?

The body of thought which seems most applicable to technological change is constructivist theory as espoused by Jean Piaget (1896-1980). Constructivism holds that the learner gains knowledge and skills through three interrelated processes:

Physical experiences
Logico-mathematical experiences
Socially transmitted information.

The learner builds his or her cognitive structure largely as an individual pursuit. This theory is useful for gaining an historical perspective, for evaluating current educational programs, and for designing curricula for a rapidly changing technological age. Knowledge gain through physical experiences is based on empirical abstraction, that through logico-mathematical experiences is reflective abstraction, and socially transmitted information consists of the arbitrary facts and rules which are agreed upon by convention (DeVries, 1987). The three are developmentally inseparable but vary in strength depending on the maturity of the individual and circumstance of learning. While much of Piaget's work was aimed at early learning, the principles have utility to all levels of education and training.

THE CURRENT EDUCATIONAL LANDSCAPE IN THE UNITED STATES

There is yet another subdivision of education, the delivery system. Again, a triad exists:

Public
Private
Proprietary

The public system is tax supported and is thus politically controlled by elected boards and legislatures. Public education at all levels in the United States is broad, varied in quality, and continually emersed in controversy, as many constituencies press for accommodation of their particular needs.

Private institutions, on the other hand, operate predominantly with tuition payments, gifts, endowments and income from various activities such as research and publications. Private schools and colleges are usually non-profit and are frequently affiliated with religious organizations.

Proprietary schools are entrepreneurial and provide highly applied training for specific skills. Student fees are relatively high in the context of their buying marketable skills. An extension of the proprietary model is direct industrial training for new or upgrading employees.

Among the three delivery systems, public is the slowest to respond to technological change. The sheer size of public primary and secondary systems make them administratively unwieldy; and the egalitarian mandate to teach all the children of whatever level of preparation and motivation, causes tremendous status quo inertia. Also, political layers of control make approval of programmatic change difficult.

Response to Crisis

Occasionally a crisis condition does cause change — but not necessarily for the better. The 1957 launching of Sputnik I by the Soviet Union sent shock waves through American political and educational circles. Quick reactions were that the country had fallen behind scientifically and that the schools were obviously to blame. A watershed of change poured forth with emphasis on more mathematics and higher level science.

The changes unwittingly led to reduced emphasis on languages, literature and communication skills; and, a generation of Americans graduated from secondary schools with perhaps improved math and science education, but definitely weaker language skills. The pendulum swung back and now most colleges require better preparation in the language arts as well as some minimal preparation in science.

But another crisis is at hand, the challenge of coping in the global arena of advancing technologies. Once again the vast public education system struggles to cope with change and is under pressure from a variety of sources. But no real improvement is yet evident.

Private primary and secondary schools are guided by the same state educational requirements as are public schools, so curricula are similar. The typically smaller sizes of private schools is both advantageous and disadvantageous. There is more personal interaction but fewer courses, particularly specialized ones such as advanced science on the one hand and vocational training on the other.

There are few proprietary primary and secondary schools, but many such day care and early learning centers, as child care becomes big business. Early learning centers, public , private and proprietary are the locus of some of the most interesting experimental education, wherein the theories of Piaget and Montessori and many religious ideas form the basis of learning.

Post-Secondary Education

In the post-secondary arena, the triad of public, private and proprietary diverge obliquely. Again, public higher education is huge, with about 2,000 colleges and universities serving ten million students. Half of all secondary graduates go on to some form of education and 80% of those go to public institutions. Public colleges and universities operate on the thesis that practically all young adults are educable, and thus enrollment standards are skewed toward openness. Undergraduate teaching is their historic domain (but graduate education is growing dramatically) and those institutions that do research are oriented toward direct application.

Private colleges and universities are the bastions of traditional liberal education, and the top ones are also the home of the most pure research. Their relative freedom from political constraints allows quicker reaction to problems and inquiry into more controversial areas. The private universities in America are also where most of the political, social and scientific elite are educated.

Post-secondary proprietary schools are highly specialized and react the quickest of all to a changing marketplace of skills. However, they are also the most vulnerable to the whims of that marketplace and suffer a high failure rate.

Education for the Design/Construct/Manage Continuum

Higher education specific to construction is generally of three types, architecture, civil engineering and construction science. The three are amazingly independent of each other and pursue the design/construct/manage continuum quite differently. Architectural education is preoccupied by design theory and aesthetics, civil engineering by functional design and construction science by practical implementation. None of the three gives much attention to facilities management, which is primarily addressed by industrial management programs. There are, in approximate numbers, in baccalaureate curricula:

95 programs in architecture
200 programs in civil engineering
130 programs in construction science
115 programs in industrial management

By far, most programs are in public institutions, but some of the best are in private colleges. By and large they deal with artificial intelligence and robotics only in a superficial manner.

EDUCATION AND TRAINING FOR THE AGE OF ARTIFICIAL INTELLIGENCE

To place the issue in Piagetian constructivist terms, any workforce needs to have a knowledge of physical things, a logical/mathematical framework , and be able to receive and transmit information in a number of directions through social means. The weight of each of the three and the sources of acquisition will vary according to a hierarchy of construction positions and responsibilities:

Management
Supervision
Skilled crafts
Unskilled workers.

There are a number of subdivisions of these ranks with many specific titles used in various regions and companies. The higher level positions require healthy doses of all three constructivist components, with the lower level positions being oriented more toward physical experience.

The growth of artificial intelligence and robotics in construction will challenge the traditional hierarchy of construction in two regards—as illustrated by the following questions:

1. Will middle management populations be reduced as artificial intelligence equipped machines become information processors and decision makers?

2. Will a crisper subdivision occur between primary workers and secondary workers, those responsible for the actual construction and those responsible for maintaining the systems and equipment?

Both questions have implications for education and training. Higher education requires regular review to avoid preparing graduates for obsolete careers. Applied training needs to address the growing need for secondary (support) workers.

Higher Education in a Stage of Flux

Most construction related higher education prepares young adults for entry level management positions with a probable move into middle management and a less probable move into upper management. For these college educated middle managers to function competitively—in fact, to be needed at all—they must be able to render services which cannot be done by a machine. They must be able to use the machines as tools for planning and decision making which transcends artificial intelligence and robotics. This suggests the broadest possible education to understand economic and social forces which shape their environments and which will dictate the direction of their companies and the decision-making inherent therein.

College level curricula in engineering have paid too little attention to construction, and curricula in construction have paid too little attention to engineering — and both have paid too little attention to good solid general education. Architectural education seems bent on re-inventing design theories with little concern about expanding technology. Better integration is necessary to maintain a relationship to the dynamically changing construction arena.

Primary vs. Secondary Workers

The second question, primary vs. secondary workers, already has antecedents both in traditional construction and in automated industries. In the age of robotics, there are strong arguments for combining the two groups into one employment category. However, it is predictable that primary and secondary tasks will remain separated, given the penchant for ever more specialized roles.

Re-evaluating Educational and Training Requirements

Let's go back to constructivist theory. All education at every level should cause students to construct their own understanding of their universe. Teachers are social transmission agents who, through dispensation of rules and fundamental facts, guide students so as to avoid their gross misdirection. Teachers should introduce physical realities and problem solving to challenge logic/math development and to stimulate self-education.

There is now a growing movement in industrialized countries toward child day-care. Rather that just custodial care, it is seen as an opportunity to introduce children to stimuli aimed at encouraging learning. While there are a number of ideas about how these learning opportunities should be introduced, there is a developing consensus that if the child is given a reassuring environment and a modicum of guidance, positive self-education will take place—and adversarial attitudes will be reduced.

It seems a great opportunity is at hand to come to grips with the changing workplace by instilling incentives to learn in preschool education. The point is not to teach facts or methods, such as spelling, adding or subtracting, but rather to introduce the elements of constructivism, to cause young children to become knowledge builders on their own. Once acquired, the knowledge building skills then serve the user for a lifetime, through formal, special and on-the-job learning. A useful model is:

Constructivism	Education		
	Formal	Special	On-the-job
Physical phenomena			
Math/logic			
Social transmission			

Fig. 3 Constructivist Model

The purpose of the model (or matrix) is as a way to view learning in a complex changing society. It is useful for planning and evaluating learning processes from preschool to college to applied training programs. Weights may be inserted in the matrix to demonstrate importance of various factors to various levels of education. The constructivist approach causes the learner to be in command of his or her own destiny by combining the elements of physical phenomena, logic/math and social transmission in the appropriate proportions for the condition at hand and the current level of development. While constructivist theory is valid for all levels, the limits of this paper cause us to focus on its application to higher education and applied training.

EDUCATION AND TRAINING SPECIFIC TO ROBOTICS IN CONSTRUCTION

There is currently no concentrated effort in education or training toward use of robotics in construction. Robotic design, with its history in manufacturing, is largely within the domains of applied physics and mechanical engineering. Application, i.e., the actual use of robots, is being supported by direct industrial training.

Among the collegiate programs relevant to the design/construct/manage continuum (architecture, civil engineering, construction science and industrial management) civil seems the most likely for development of robot processes because of its research orientation. Architectural programs are moving strongly into computer aided design, and this may lead to experimentation in building types which are adaptive to robotics. Construction students are working with computer driven estimating, scheduling and resource management. Industrial management students are using artificial intelligence to aid decision making in factory layout, control and maintenance. So the stage is set for advancement toward robotics in design, construction and maintenance. But the current fragmentation of effort is illustrated by a comparative model:

Construction and Management Education - Existing

	Arch			Civil			Constr.			Ind.Mgt.		
	F	S	O	F	S	O	F	S	O	F	S	O
Phys. Phenomena	5	10	10	4	5	6	4	8	10	3	4	5
Logic/Math	3	3	3	5	4	3	3	3	3	3	2	2
Soc. Trans.	8	6	4	10	8	8	8	6	4	10	8	8

Fig. 4 Existing Comparative Education

F, S, and O are formal, special and on-the-job and are indicative of traditional classroom instruction, special projects and internships or cooperative education respectively. While there may be arguments on specific weights, it is clear that there is currently too much dependence on socially transmitted information from faculty and too little emphasis on logic/math as the basis for building individual knowledge bases. And, these patterns tend to reinforce separation among the disciplines. Constructivism is not practiced in undergraduate technical education.

Community of Scholars

An age old notion is that a college is a community of scholars. Over time this idea has given way to specialization and fragmentation in higher education. Each department jealously holds on to its own area of interest, course work and research. Certainly this is the case with construction and management related programs. A recommendation is that collaborative efforts should lead to combined projects in which academic integration take place. Students in the four disciplines should perform in combined learning projects in which experimentation with physical phenomena and exercises in logic cause them to develop interactive skills and to strengthen their constructivist knowledge base. it would become a community of student scholars.

Construction and Management Education - Recommended

	Arch			Civil			Constr.			Ind.Mgt.		
	F	S	O	F	S	O	F	S	O	F	S	O
Phys. Phenomena	6	8	10	6	8	10	6	8	10	6	8	10
Logic/Math	10	10	8	10	10	8	10	10	8	10	10	8
Soc. Trans.	6	2	4	6	2	4	6	2	4	6	2	4

Fig. 5 Recommended Integrative Education

The key points of the recommended model are that the pattern of socially transmitted rules and facts from faculty should be reduced and logic/math and physical experiences should be increased to allow more opportunity for building of individual knowledge bases. The model also suggests projects which will allow integration of the disciplines. And internships or cooperative education is encouraged as hands-on experience where developing knowledge may be tried in a real-world setting. It may be presumptuous that all four disciplines have the same weights, but for them to interact as a community of scholars, some benchmarks are recommended.

This whole model is dependent on students having the motivation and initiative necessary to proceed on individual pursuits of knowledge building. This suggests that primary and secondary education adopt constructivist models to prepare students for self-initiated learning. This further suggests a long term approach to educational change. In the shorter term, colleges and universities should strive to create conditions wherein academic integration can thrive. Efforts across departmental lines could lead to combined projects in the application of robots to construction.

Perhaps in the real short term such integration can take place only at the graduate level. With the growth of graduate education and fewer curricular strictures therein, a relatively quick move could be made. However, the goal should remain for better integration in undergraduate education.

Applied Training

An opportunity exists for applied training in vocational secondary schools, two year college programs and proprietary training centers. Vocational schools are the great untapped resource of American education. Given their orientation to mechanical and automotive training, robotics should naturally follow. Two year college programs are a potential source of foreman training for robotics. Proprietary training while having the flexibility noted earlier, may not be able to carry the high cost of equipment required by training.

Craft Training

	Existing									Recommended								
	Voc.			2 yr.			Prop.			Voc.			2 yr.			Prop.		
	F	S	O	F	S	O	F	S	O	F	S	O	F	S	O	F	S	O
Physical phenomena	3	4	6	2	4	6	2	2	6	4	10	8	4	10	8	4	6	8
Logic/Math	2	1	1	4	2	1	1	1	1	6	6	4	8	6	4	4	4	4
Social transm.	5	4	4	8	6	4	5	4	4	5	4	4	6	4	4	5	4	4

Fig. 6 Applied Training

As in management education, an overall upgrading is recommended, with emphasis on the interrelationship of logic/math to physical phenomena. The products of these training programs could become foremen and craftsmen in either primary or secondary roles.

CONCLUSION

Whereas there is little current education or training for robotics in construction in the United States, there is an ample network of institutions in which to introduce programs at various levels. On a broad and future oriented basis, a constructivist approach is recommended to begin in preschool learning. If followed through primary and secondary education, an abundant cohort of self-directed personnel will be prepared to engage technological change. This cohort could then subdivide into formal education, special training or on-the-job experience—or a combination of all three, as particular needs and situations prescribe.

In the more immediate context, preparation for the coming of robotics and artificial intelligence to construction will be aided by developing better integration of the existing construction and management disciplines (architecture, civil engineering, construction science and industrial management) both in the academy and in practice, so that the elements and implications of technological change in construction may aid cohesion rather than reinforce the existing adversarial relationships. Internships can enhance college education and smooth the transition from school to practice.

Training in the near term can take advantage of the combined resources of vocational schools and two year colleges, both of which are well equipped to move to mechanical aspects of robots, both in primary and secondary contexts. Proprietary schools, with their strong entrepreneurial orientation, are able to respond the quickest, but will be impaired by the capital investment required of credible training in robotics. On-the-job experience will remain the most directly applied method of preparing workers to use and maintain robots. However, industrial owners will expect the tax-supported public education system to start providing better job entrants.

The global marketplace of technology will cause all industrialized nations to look closely at their educational systems. It seems valid that a marketplace of ideas in education, both theory and application, will be useful to all nations in a spirit of cooperation and mutual improvement. Constructivism itself is international, having been introduced by Piaget, a Swiss, and having been nurtured and developed by many researchers and practitioners in a number of countries.

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