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A Global Study of Undergraduate Electrical Engineering Curricula*

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Traditionally, curricula of a technical nature have been characterized by rational, orderly statements of objectives. A recent trend, however, is for some electrical engineering curricula to become situation-based in response to self-interest factors and overlapping personal frameworks of decision-making. This article reports quantitative data from universities in 12 sampled countries with regard to the uniformity and diversity in their undergraduate electrical engineering curricula, and accounts for the empirical findings in terms of modern theories of curriculum construction, development and implementation.

INTRODUCTION

THIS PAPER reports the preliminary findings of an empirical study of uniformity, diversity and changes in sampled undergraduate electrical engineering policies and curricula in 12 different countries. Data collection occurred by means of a survey questionnaire constructed using the theory of educational modelling, designed to examine the natures, structures, methods, quality and effectiveness of performance of engineering curricula in leading tertiary centres throughout the world.

A number of factors have been recognized from research as important in successful educational change. Most of them are concerned with communication, negotiation of meaning and co-operative working, all of which are essential aspects of participants collaborating in the control of change processes [1–3]. Even so, the possibility of actually achieving a desired result in any change process has been determined to be about 50% [4].

An interesting and important difference between the western and eastern sectors of the world lies in the emphasis that is placed upon different aspects of the change process. According to Lovat and Smith, westerners spend most time on the generation of possible solutions, paying little attention to defining the problem/situation and why the change is needed. Hence, there tends to be little opportunity for people to clarify their perceptions of a problem and its context, or to explain their understandings of why a particular change is necessary. This means that a good deal of the discussion about possible solutions tends to be omitted—because people are responding to the proposed solutions without clarifying their different perceptions of the problem and its situation. As a result, people may differ about an offered solution, not because of the specific answer itself, but because of a difference in perception about the problem for which the solution is proposed.

In Japan, in business, for example, the emphasis is reversed. Much time is spent discussing the problem, people's perceptions of it and the problem context. At first, very little time is consumed discussing possible solutions. It is only after a great deal of time has been devoted to identifying and defining the problem, and clarifying why the change is necessary, that possible answers are discussed. Usually, most of the solutions will have arisen indirectly during the process of clarifying the reasons for the change. As a natural consequence of the emphasis on delineating the problem, its ramifications and its context, if and when possible changes have to be implemented, most of the people involved do not have to be convinced at that final stage of the need for change [4].

If curriculum change is to be successful, then, it seems there should be a great deal of emphasis and time spent on developing both an explicit and a shared perception of the problem, with clearly identified and shared reasons for the change where appropriate.

BACKGROUND

For more than 40 years a *normative* approach has characterized the development and implementation of engineering curricula. It provides a sequence of steps which its writers say should be

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used when technical interests of control are of primary importance. Normative approaches have included the well-used *objectives* model of Tyler [5] and the *rational* models of Taba [6] and Wheeler [7].

An alternative approach to curriculum development is the *descriptive* or *procedural* model. It describes the actual steps, procedures and processes undertaken by a group of curriculum planners. Such descriptive or procedural approaches have been promulgated by Walker [8], Stenhouse [9], Yinger [10] and Smith [11]. Whereas the *content* step in the objectives model tends to be subservient to the attainment of the objective, the procedural approach sees it as having value in itself. The business of curriculating is therefore a subtle one, requiring sensitivity to the peculiarities of the form of knowledge with which one is dealing. For Stenhouse, the objectives model is far from subtle. It imposes a standard pattern on learning everywhere, and reduces the effects of learning to a pre-determination of specified skills. Indeed, Stenhouse maintains: 'Education as induction into knowledge is successful to the extent that it makes the behavioural outcomes of the students unpredictable' [9].

These descriptive or procedural approaches arose out of the recognition that not all people are consistently logical and rational human beings who will simply change their ways as soon as reasonable argument and evidence are presented. What the objectives model omits is the fact that human beings, even engineers at times, operate from their own preferences, and that such interests are not necessarily logically derived. Human beings are also characterized by ranges of personal feelings and diverse ways of seeing and intuiting the world, and of creating individually unique designs.

The rational/empiric strategy of objectives also assumes that there is one form of logic and one form of reality; that every person's logic and intuition will be similar; and that empirical data are objective, value-free and neutral. Clearly this is not always true, even for undergraduate electrical engineering students. There are many logics in various contexts, perhaps as many as there are people. Different forms of logic rely on perceptions, curiosities, creations, insights, ideas, concepts and designs which are subjective, and which are derived partly from personal interests [12].

Even in basic engineering education, failure can result from the use of curriculum strategies which are purely rational/empiric. During the 1960s and 1970s, for example, millions of dollars in the United States, Australia, and other countries were priority channelled into the preparation of kits of physics curriculum materials (PSSC) by *experts*. The kits of apparatus and manuals were then placed in schools and colleges with back-up reasoning and evidence about why they should be used. The practical outcome, however, was that many of the kits remained on shelves untouched or hardly used and, in many cases, the proposed changes, although *logical* to science instructors, were singularly unsuccessful. Apparently individual, personal preference or self-interest will always be the ultimate filter, the bottom line, of innovative curriculum development.

TEACHER CURRICULUM PLANNING: A SUMMARY OF RESEARCH FINDINGS

Lovat and Smith have recently summarized the major findings from research into the ways in which teachers and instructors undertake curriculum planning. Eight of these are as follows:

- Teachers' planning is even more complex than all the curriculum approaches discussed above.
- Commencing the planning process by specifying objectives might make teachers less aware and less sensitive to the needs of students.
- While teachers' written plans consist only of an outline of topics, or a sketchy list of important points, it is teachers' mental plans or images that are most important in providing a picture of what is intended should take place during the period of instruction.
- Teachers appear to undertake their planning within an operational space of possibilities or frames which they define perceptually.
- A teacher's beliefs and perceptions are very important influences on the planning process and on decisions that are made.
- A most important factor in teachers' curriculum planning is information about the learners, their abilities, their interests and beliefs.
- Factors about the teaching context, such as materials and resources available, are also important in teachers' planning.
- The tasks in which the learners will engage appear to be the central focus of teachers' curriculum planning.

It is clear that these research findings should be taken into consideration at least when planning a curriculum in electrical engineering education for the last decade of the 20th century.

WHAT IS CURRICULUM?

Presented below are a number of definitions of curriculum used by different people at various times during the last 60 years. According to Lovat and Smith, some are composite definitions from one or more sources from a particular historical period. Others are specific to one source:

- Curriculum should consist of permanent studies—grammar, reading, rhetoric, logic, mathematics and the greatest books of the western world (1936).
- The curriculum should consist entirely of knowledge from the disciplines (1962).
- The curriculum is all the experiences a learner has under the guidance of the school (1970).

- The curriculum is the syllabus, a course of study or subjects (1971).
- The curriculum is a vital complex movement of people and things in a free-wheeling setting (1973).
- The curriculum is all planned learning objectives or desired consequences of the instructor for which the school is responsible (1970).
- Curriculum produces plans; instruction puts them into action (1965).
- Curriculum is the educational experience, the educational journey (1975).
- On the one hand, curriculum as intention comprises a progressively modifiable plan of areas of learning and growth for an individual or a group of learners focused upon an educational centre, incorporating a set of objectives, a set of learning experiences and suggestions for their organization and techniques for evaluation of learning outcomes. On the other hand, curriculum as reality is what actually happens to the person or persons, arising from a complex network of interactions between people responding to a diverse array of influences, explicit and implicit, human and physical (1982).

In addition:

- Curriculum is the complimentary relationship of a syllabus and its related teaching and learning processes [13].

It is apparent that many definitions of curriculum exist, each one embedded in its own set of assumptions, values and perspectives. A particular concept of curriculum also often depends on which level of the education system is being addressed. Curriculum, then, is concerned with making value-based choices from alternatives, and is context specific. It is essentially a practical activity which is creative and artistic [14,15]. It has aspects of product, process, intention and reality; and both normative and descriptive perspectives.

TECHNICALLY ORIENTED CURRICULA

Finch and Crunkilton have identified 10 basic characteristics and emphases of a technical curriculum which distinguish it from other educational curricula. These include: *orientation* (with its controlling purpose being the preparation of persons for useful, gainful employment in the work world); *justification* (in terms of community needs and demand); *focus* (by integrating student knowledges, skills, attitudes and values in simulated and realistic work settings); *in-school success standards* (in hands-on or applied performance, with criteria used by teachers often being standards of the work world); *out-of-school success standards*; *community relationships* (maintaining strong ties with a variety of industry and business employers and their needs); *federal involvement* (in the maintenance of standards, clock hours, funding, etc.); *responsiveness* (to rapid technological changes in the world of work and of society); *logistics* (involving the complex bringing together of the proper facilities, specialized equipment, quality supplies, maintenance and instructional resources, which are critical to success or failure); and *expense* (such as operating costs, purchase of consumables and updated equipment, travel to work locations, and accommodation space for office equipment).

They then proceed to develop an eight-point rationale for curriculum development in vocational and technical education to try to circumvent the pitfalls of haphazard syllabus development, creeping obsolescence and irrelevance. The curriculum, they say, should be 'school and community data-based; dynamic; characterized by explicitly stated outcomes; fully articulated; realistic; student-oriented; evaluation-conscious' and 'future-oriented' [16].

INDIVIDUAL TEACHERS' THEORETICAL CURRICULUM FRAMEWORKS

Research that has investigated teachers' curriculum planning processes suggests that teaching is a very complex process, with hundreds of interactions possible even in a single teaching session. The size of a teacher's perceived curriculum decision-making space is affected by two things. First is the number of curriculum decisions that a teacher perceives have already been made by people or groups other than the teacher. Second is the number of options which a teacher perceives are available for those decisions that have not been made by others. Each available option creates a frame space. Together, the overlapping frames produce a decision-making space for each teacher [4].

It is important to note that this space, and the individual frame spaces, are not static but dynamic. They change for the same teacher from day to day, from one group of learners to another, and from one curriculum subject to another. The teacher's decision-making space is like a series of overlapping picture frames. Inside each frame lie the options for one particular factor. Together, the overlapping frames for each factor produce an overall decision-making space, perceptually defined.

On a larger scale, Fig. 1 depicts a theoretical pattern for broader overlapping frameworks of basic components of undergraduate engineering curricula, to a greater or lesser degree, depending on the interests and abilities of the instructor to impart subject matter creatively with relevant applications. This outline of curriculum possibilities—first proposed in 1983 by one of the authors—is developed more extensively elsewhere [17].

To sum up, the question of syllabus is always a thorny one for individual teachers and lecturers [18], and it is against this background that the find-

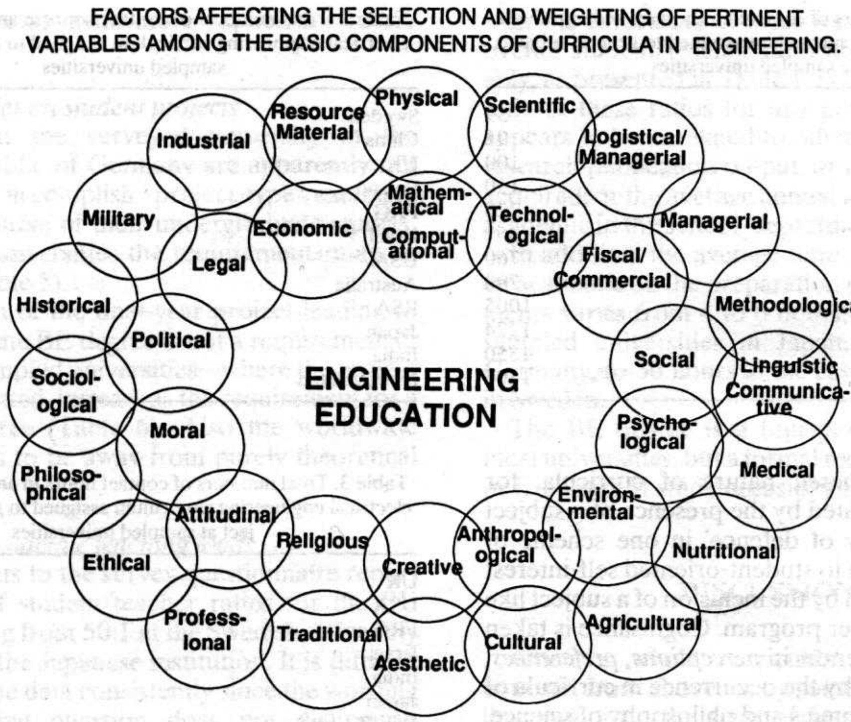

Fig. 1. Designing a curriculum in context.

ings of the current investigation into undergraduate electrical engineering curricula in 12 different countries are now presented.

THE DATA-GATHERING INSTRUMENT

A complete edition of the first version of the questionnaire used in the initial pilot survey is obtainable from the authors. Only the more important and pertinent undergraduate findings are presented in this paper.

The theoretical model adopted for the construction, content and developmentof the questionnaire is that of educational modelling published elsewhere [17]. It is suitable for research processes requiring repetition for several consecutive steps until a final version is reached.

As anticipated, the wording of the survey questions is not always appropriate for different countries. In Italy and Japan, for example, the concept of 'contact hours', i.e. the cornerstone of several questions, does not exist. (A revised version of the piloted questionnaire—adjusted in the light of the preliminary findings discussed in the rest of this article—is available from the authors, on request.)

FINDINGS

One-third of the respondents report that their undergraduate electrical engineering curricula are industry-oriented; one third science-oriented; and one third both (e.g. with fundamental principles being applied to current technology by the academic staff as a matter of departmental policy).

Diversity in degree of specialization

Although respondents differ widely in regard to what they perceive as *general* subjects in the undergraduate electrical engineering curriculum, some respondents classify only three of their subjects as 'general', whereas others list up to a dozen. These include English, a foreign language, technical report writing, mechanical drawing, political economy and Marxism, programming languages, communications, economics, astronomy, accountancy, philosophy of science, literature, psychology, sociology, computer science, ergonomy, defence military preparation, sport, politology and economy of defence. In some cases engineering mathematics, physics and chemistry are also classified as 'general' subjects, with the numbers of contact hours assigned for these subjects ranging from 59 in one Israeli university to 1500 hours in one Swedish university (Table 1).

The unexpected range of subjects found above partly validates and explains the postulated need for a descriptive/procedural model of curriculum theory *in addition to* the traditional objectives model. A *normative* model of curriculum development could scarcely have been used by the reader of this article to predict accurately the range and natures of such a wide variety of courses existing in current undergraduate electrical engineering programs.

Table 1. Total numbers of contact hours in an undergraduate electrical engineering curriculum assigned to *general* subjects at the sampled universities

Israel	59
FRG	91
USA	100
UK	130
RSA	220
Australia	351
India	760
New Zealand	790
Japan	1005
China	1224
Poland	1350
Sweden	1500

The *situation-based* nature of curricula, for example, is illustrated by the presence of a subject such as 'economy of defence' in one scheme of courses. Attention to student-oriented self-interest factors is indicated by the inclusion of a subject like literature in another program. Cognisance is taken of students' differences in *perceptions, preferences, beliefs and values* by the occurrence in curricula of subjects like economics and philosophy of science. Subtle *sensitivity to students' peculiarities and feelings* may be indicated by the inclusion of psychology as an option in other curricula. A reluctance to *pre-determine* specified skills for the whole curriculum can be perceived by the incorporation of subjects such as sociology and sport in some university programs.

Furthermore, combinations of subjects which a particular student may choose are *unpredictable*—e.g. an individual might opt for astronomy together with ergonomy. The dynamic natures of other curricula are reflected in the choice of foreign languages in some universities, whereas the *future-orientedness* of others might be indicated by an emphasis on defence/military preparation and accountancy.

To sum up, the preliminary data collected in the survey to date appear to provide evidence in support of the theoretical curriculum paradigms postulated as valid frameworks for the current global pilot study of undergraduate electrical engineering curricula.

Diversity in basic science content

Over the dozen universities sampled, the numbers of contact hours assigned to chemistry as a subject range from 0 hours, at five institutions, to 164 hours at one university in New Zealand (Table 2); the numbers of contact hours allotted to physics as a subject range from 0 at one British univerity to 800 in a Swedish university (Table 3); and the contact time assigned to mathematics varies from 12 to 750 hours (Table 4). However, it has already been pointed out that, at some universities, the fundamental principles of physics and mathematics are applied both within and to specialized engineering technology as integral subjects in their own right (e.g. in Britain), rather than necessarily being taught as separate subjects on an individual basis, so the data presented must be interpreted cautiously.

Table 2. Total numbers of contact hours in an undergraduate electrical engineering curriculum assigned to *chemistry* at the sampled universities

Sweden	0
China	0
UK	0
Poland	0
FRG	0
Israel	3
USA	8
Australia	81
RSA	88
Japan	90
India	90
New Zealand	164

Table 3. Total numbers of contact hours in an undergraduate electrical engineering curriculum assigned to *physics* as a subject at sampled universities

UK	0
USA	9
FRG	16
Israel	17
India	90
Japan	150
New Zealand	164
Poland	180
China	192
RSA	330
Australia	378
Sweden	800

Table 4. Total numbers of contact hours in an undergraduate electrical engineering curriculum assigned to *mathematics* at the sampled universities

USA	12
FRG	23
Israel	26
India	90
UK	140
Japan	150
New Zealand	284
China	315
Poland	345
Australia	378
RSA	704
Sweden	750

Diversity in basic professional subjects

The respondents who answered the survey questionnaire list a total of more than 50 subjects which they consider to be basic professional subjects in undergraduate electrical engineering curricula. No doubt many of these subjects overlap in content. The Japanese respondent also regards mathematics as a basic professional subject.

However, the total number of hours quoted as assigned for these basic professional subjects ranges from 17 hours to 600 hours, which appears anomolous, so the wording of this question has been revised and made more explicit for future surveys.

Diverse policies on student projects

Students at the surveyed university in the Federal Republic of Germany are apparently not required to accomplish project-type exercises during the course of their undergraduate studies, yet at other universities the requirements may be extensive (Table 5).

Preparation of the final-year project leading to the award of the BE degree is not a requirement at four of the sampled universities—where the project is to be submitted, instead, as the requirement for a Master's degree (Table 6). Also the worldwide trend appears to be away from purely theoretical projects.

Diversity in academic teaching loads

Respondents to the survey questionnaire report a diversity of student/teacher ratios for the BE degree ranging from 50:1 at the Swedish university to 140:60 at the Japanese institution. It is difficult to interpret the data consistently since the wording of the original question does not distinguish between the numbers of full-time and part-time teachers available for student instruction.

Table 5. Number of project-type exercises which students have to accomplish during their undergraduate engineering studies at the sampled universities

FRG	0
Japan	0
Australia	1 major
China	1
Poland	2
Sweden	very few
USA	5
India	6
New Zealand	10
Israel	10
Canada	many
UK	up to 25
RSA	36

In the laboratory courses for a BE degree, the overall student/teacher ratio also varies appreciably, as presented in Table 7. However, the magnitude of these ratios for any particular university appears to be unrelated to other variables such as research publication output, or number of patents acquired, or the average annual teaching load of an academic in the school/department concerned.

In addition, the average time per week spent by an academic on the preparation of teaching assignments varies from 4 to 6 hours, in the case of the sampled universities in Japan, USA and West Germany, to 30 hours in the case of the university in Sweden.

The BE degree is a four-year qualification in most universities, but a formal requirement of three or five years of study occasionally occurs.

DISCUSSION

When a whole curriculum is devised and imposed from above, or by some external controlling authority, the type of learning that can be effected and examined tends to be of a technical nature. However, when the form of a curriculum becomes collaborative, it becomes guided by communication between participants or self-reflection on their parts [19]. This begins to account for the diversities found to exist in undergraduate electrical engineering curricula throughout the world with respect to their philosophical orientation, degree of specialization, amount of basic science content, the nature of professional courses offered, policies towards projects, and the teaching loads of members of the academic staff.

Lovat and Smith advocate that the essential aim of curriculum work is to make the best, the most effective, and the most justifiable decisions. The best decisions will bethose that are taken:

- Deliberatively.
- In a group process.

Table 6. Average time required by an engineering student to prepare final-year projects of different natures at the sampled universities

	BE	ME or M.Eng.Sci.	% of projects: Theoretical	Experimental	Mixed
Australia	351 hours	$1\frac{1}{2}$ hours	20	30	50
Canada	110 or 220 hours	2 years	?	?	?
China	14–18 weeks	$1\frac{1}{2}$ years	10	10	80
FRG	–	1000 hours	20	20	60
India	180 hours	1100 hours	25	25	50
Israel	110 hours	800 hours	0	0	100
Japan	6 months	2 years	20	50	30
New Zealand	150 hours	1200+ hours	?	?	?
Poland	500 hours		50	20	30
RSA	320 hours	2 years	10	10	80
Sweden	780 hours		5	30	65
UK	360 hours	360 hours	0	0	100
USA	0	12 hours	30	30	40

Table 7. Average annual academic teaching load and overall student/teacher ratios in the laboratory courses for a BE degree at the sampled universities

	Student/lab teacher ratio	Average annual academic teaching load hours
Sweden	30:1	250
Canada	20:1	4 × term courses
RSA	20:1	250
China	15:1	210
USA	15:1	4 courses, i.e. 2 per semester
UK	12:1	540
India	10:1	150
New Zealand	8:1	300
Poland	6:1	210–270
Israel	6:1	6 weekly
Japan	140:30	225
FRG	8:1	500
Australia	12:1	250

- Identifying, in a critical manner, the possible alternatives.
- Considering the consequences of choosing each alternative.
- Making the choices explicit.

In any curriculum work the key questions to be answered are:

- What knowledge is of most worth to this particular group, in respect to information, concepts, skills, activities, feelings, norms and beliefs?
- What tasks (activity/resource/content) are most effective in assisting the students to acquire this knowledge?
- What is the most appropriate way to sequence these tasks?
- What is the most appropriate way to organize (interrelate) these tasks?
- What is the most appropriate way to structure (provide instructions to complete effectively) these tasks?
- How will I know when the students have acquired the knowledge?

Once answers to these questions have been derived, and curriculum alterations are envisaged, the first and most important thing to note about the contemplated changes is that inevitably they will be concerned with feelings and perceptions. Change is about challenging a person's beliefs, perceptions, traditional ways of working and long-held and established practices. Doing any of these things must produce strong feelings and, if these are not dealt with effectively, then intended changes may not last for very long.

The second important thing to notice about curriculum change is that it involves conflict. In fact, it is probably true to say that if a change does not involve some degree of contest, then it is probably not very important or significant. Thus curriculum designers must expect that there will be dissonance, accept such struggle as a positive force for change, and plan ways to manage the conflict as part of the strategy for change, with carefully planned requisite extra support.

Rogers and Shoemaker [20], Havelock and Havelock [21] and Mazoudier[22] suggest that an effective change agent is usually chosen because he/she has the following characteristics:

- *Empathy*, or the ability to put him/herself in the place of the clients.
- *Homophily*, or having the same experience and background as the clients (e.g. in engineering curriculum change, being a lecturer in engineering while being a change agent).
- *Credibility*, which is strongly related to homophily, but also includes a perception by the clients that the change agent is different from them, in the sense that he/she is well informed about the change and has the skills and knowledge to be able to help them change.
- *Hard working* and active with clients, and building strong relationships with clients.

A plausible explanation for the wide variations now shown to exist in undergraduate electrical engineering curricula throughout the world might well be found in determining factors such as these.

CONCLUSION

Curricula in electrical engineering across the globe vary appreciably in regard to their philosophical orientation, degree of specialization, inclusion of basic science content, the nature of professional courses offered, policies towards theoretical and practical projects, and the teaching loads of lecturing staff. While diversity can be justified in terms of modern theories of curriculum development, there is also a challenge to the individual lecturer to reverse the disconnectedness of so many aspects of the present engineering world, using Figure 1 in the planning of creative instructional presentations.

There is a challenge to develop a personalized engineering curriculum overlay, to enrich the agreed basic subject matter, which is not based on the separateness of knowledge from life and being, but upon their inherent unity and integration with all the gifts and qualities of humanity. There is a challenge to each lecturer to construct, in a critical manner, a personal undergraduate electrical engineering curriculum which:

- Has *peaceful and loving visions of the future* rather than a retreat behind introspective barriers of disconnection, division and isolation.
- Fosters an *enrichment of great hearted individuality*, in preference to the pursuit of narrow self-interests of individualism.
- Has the purpose of *developing bridges* across broken linkages, and fruitful cohesion among a plurality of disparate interests.
- Has a sense of *commitment to healthy community relationships* to balance the tendency towards

uncaring autonomy, independence and individualistic freedom from long-term human responsibilities.

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