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Educating Engineers for the Environment: a Pilot Study on how Students Assess the Concept in Engineering Curricula*

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Environmental education, especially the principles underlying sustainable development, has become an increasingly important issue in engineering over the last few years. Questions that spring to mind are whether these issues are currently being addressed in engineering curricula and whether it is really necessary for engineers to be environmentally aware and educated. This paper provides comparative data obtained from a sample of engineering students in Australia and in the Republic of South Africa on the current situation in engineering education.

INTRODUCTION

The revolutionary movement concerning the environment basically began in the early 1960s. At that time it was becoming obvious that our faith and dependence on modern technological and scientific developments had had serious repercussions for the environment. This sharpened the awareness that such environmental consequences could not be easily reversed by the same technology [1]. The environmental problems recognised three decades ago still confront us today. Presently, we may see quantitative progress in our technical machines and our economic statistics, but in our lives we may experience only qualitative regressions [1].

Such regressions include evidence of a dramatic increase in the level of carbon dioxide in the atmosphere due to the burning of fossil fuels, contributing to further global warming. The use of CFC products has contributed to the depletion of the ozone layer which shields us from harmful ultraviolet rays. Environmental problems are increasing at an alarming rate and extending to all segments of the environment (air, water, land and the human environment).

A series of major environmental events and conferences have been held over the last three decades, suggesting the importance of these environmental issues to mankind. A listing of these events is shown in the appendix (Table 2).

ENVIRONMENTAL IMPACT

Studies have been undertaken to measure and describe the impact on the environment of a number of factors. A formula (1) describing the environmental impact has been developed [2]. According to this formula, environmental impact is governed by three major factors:

- Population (number of people)
- Development (wealth, energy resources)
- Environment (air, land, water, human)

M.F. Jischa observes how these three factors pose a threat to sustainability, stating that there are three major death traps confronting humanity today [3]:

- The demographic trap, as a consequence of the population explosion.
- The supply trap, as a result of shortages in non-renewable resources.

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* This paper was awarded the UICEE diamond award (equal first grade with two other papers), by popular vote of Congress participants, for the most significant contribution to the field of engineering education
*As Director of the UICEE, Zenon Pudlowski declined to accept the award, which was accepted by Duyen Nguyen

$$\text{Environmental Impact} = \text{Population} \times \frac{\text{Products \& Services}}{\text{Person}} \times \frac{\text{Resources (Energy)}}{\text{Products \& Services}} \times \frac{\text{Impact}}{\text{Resources (Energy)}}$$

$$= \text{Population} \times \frac{\text{GNP}}{\text{Population}} \times \frac{\text{Resources (Energy)}}{\text{GNP}} \times \frac{\text{Impact}}{\text{Resources (Energy)}} \quad (1)$$

- The disposal trap, due to the general problems of the environment, eg greenhouse effect, depletion of the ozone layer, deforestation, rise in pollutants, build-up of waste, loss of biological diversity.

ENVIRONMENTAL VIEWS

There are basically two opposing views concerning the impact of these factors on the environment. The first view is a rather pessimistic one, and is held by the Club of Rome. Members of the Club advocate the idea of *limits-to-growth*. They believe that the avoidance of the deterioration of the environment and the preservation of a healthy environment can only be achieved if humans apply limits to the growth of population, development and environmental pollution.

The second view is an optimistic one and is perceived by a group of members of the Hudson Institute. They believe that technological and economic development will be the resolution to all environmental problems and see growth as a stimulus rather than an impediment to environmental health. Table 1 presents the two views in detail.

Having been presented with these two conflicting views, a fundamental question arises: which of the two views should be adopted in order to achieve a sustainable world? Neither of these views can adequately assist in building the bases upon which to form our response to the environmental issues we are facing today [2]. What we need today is to transform our current values, attitudes, education and practice so that they are confined within the environmental and sustainable framework.

RAISING THE PROFILE OF ENVIRONMENTAL EDUCATION IN ENGINEERING

It has become clear in recent times that engineering has been taught completely outside the environmental context. Students were educated for a particular engineering discipline with emphasis on technical aspects of the discipline and with no relevance and reference to the environment. This has become an impediment to the development of a complete engineering education, and a tremendous hindrance to human resources development in engineering. It was recognised that an urgent transformation of engineering education was necessary in order to cope with the changes of modern times.

In particular, it was realised that changes to engineering curricula were needed in order to inject environmental and sustainability concepts, topics and ideas into engineering theory and practice. Thus, subjects dealing with issues of the environment and sustainable development needed to be introduced to engineering curricula in order to provide engineers with the knowledge, skills, awareness and attitudes to participate in the resolution of environmental problems and, in the first instance, to avoid creating such problems themselves. The following is an attempt to specify the meaning of these qualities and attributes in relation to the environment:

- Knowledge: to help social groups and individuals gain a variety of experience in, and acquire a basic understanding of, the environment and associated problems.
- Skills: to help social groups and individuals acquire skills to identify and solve environmental problems.
- Awareness: to help social groups and individuals acquire an awareness and sensitivity to the total environment and its allied problems.
- Attitudes: to help social groups and individuals acquire a set of values and feelings of concern for the environment and the motivation to actively participate in environmental improvement and protection.
- Participation: to provide social groups and individuals with an opportunity to be actively involved at all levels in working towards the resolution of environmental problems [4].

It is vital that the above qualities and attributes be developed and enhanced through engineering education if future engineers are to play a significant role in the protection, management and maintenance of the environment. This important transition in the development of contemporary curricula demonstrates that issues concerning the environment and sustainable development naturally form an integral part of engineering curricula.

Table 1: Opposing environmental views held by the Club of Rome and the Hudson Institute.

CLUB OF ROME (LIMITING GROWTH)	HUDSONS INSTITUTE (UNLIMITED GROWTH)
Finite/Limited • Supply of natural resources • Supply of agricultural/arable land • Capacity of the environment to absorb pollution.	**Infinite/Unlimited** • Supply of natural resources • Supply of agricultural land
General remarks Since the industrial revolution there has been an exponential growth in population, consumption of natural resources, production *(both industrial and agricultural)* and pollution.	**General remarks** The future growth in population, consumption of natural resources, production *(both industrial and agricultural)* and pollution may slowly decline because of progress in technology and economic development.
Prediction An unlimited growth in the consumption of natural resources, the use of agricultural land and the accumulation of pollution in the environment will result in the collapse of the environment.	**Prediction** Any growth in population, natural resources, production and pollution will be resolved by technological and economic means.
Consequences • Experience a dramatic reduction in population and production as a result of either depletion of natural resources and increase of environmental pollution.	**Consequences** • Stabilisation of population will be maintained by the levelling of population growth experienced by post-industrial societies. • Infinite supply of natural resources available because of advances in technology that can provide substitutes to accommodate for depleted resources. It is also predicted that renewable resources will be the main energy source of the future. • Infinite supply of agricultural land with the aid of new agricultural and food production techniques. • Environmental technology will resolve the short-term environmental problems.
Solution Apply limits on population and industrial growth.	**Solution** No limits to economic growth.

DEVELOPMENT OF ENVIRONMENTAL ENGINEERING DEGREE PROGRAMMES

Environmental education received recognition from the Belgrade Charter, which emerged from the *Belgrade International Workshop on Environmental Education* convened in 1975 as part of a UNESCO-UNEP programme [5]. In the past, engineering education failed to consider the environment in engineering curricula, but now, in the 1990s, certain questions regarding the study of the environment have been discussed and concerns raised, and reforms have taken place in order to address these issues in engineering education.

Such changes have led to the emergence of intensive environmental engineering programmes, a process that is now also being driven by the realisation of the need to deal with sustainable development [6].

In the last few years environmental engineering has been receiving rising attention and rapidly seems to be reaching the stage of becoming an engineering branch in its own right. In Australia most engineering faculties now offer environmental engineering courses in their undergraduate programmes and some universities are in the process of establishing environmental engineering departments, providing degrees in environmental engineering [6].

It was not until the 1990s and the establishment of a bachelor degree in environmental engineering that environmental education was addressed at Monash University, but the area is still experiencing problems in finding a way into general engineering.

According to a pilot study carried out by P. Vare with a sample population of engineering students, this situation appears to be even more problematic for South African institutions [7]. An *Education and Communi-*

cation for Sustainability in Africa (ECOSA) survey questionnaire was designed to provide an overall picture of environmental education provision in Africa. The 13 countries that responded to the questionnaire stated that there was no provision for environmental education at the tertiary level. It was also reported that existing school curricula do not appear to reflect the total environment (ie the social, economic, cultural and ecological context) as experienced by young people [7].

Environmental education should be included in all disciplines and levels of the formal engineering education curricula in order to foster a sense of responsibility for the state of the environment and to teach students how to monitor, protect and improve it. The attitudes of engineering teachers will be crucial for increasing students' understanding of the environment and its links with development [8]. Engineering educators must move out of conventional education and provide more flexible engineering curricula that can keep up to date with dynamic systems.

PILOT STUDY

To assist in finding answers to these important questions, as well as to compare the situation in South Africa and Australia, a questionnaire was developed and was distributed to two hundred students. Two institutions in the Republic of South Africa (Technikon Pretoria and Peninsula Technikon) and one in Australia (Monash University) were surveyed and compared.

The objective of the survey questionnaire was to provide valuable information on the availability of course material on sustainable development and environmental issues and topics in engineering curricula. The results are shown and discussed below. The number of surveyed students and the number of returned survey questionnaires are shown in the table below:

	Survey distribution	Return survey
South Africa	100	81
Australia	100	47
Total	200	128

TEST SAMPLES

Q1. *Are sustainable development and environmental engineering education issues of interest to you?*

	South Africa	%	Australia	%
YES	72	92.1	37	78.7
NO	9	7.9	10	21.3
TOTAL	81	100.0	47	100.0

By observing the statistics it can be generalised that engineering students are very much interested in the issue of sustainable development and environmental engineering education. The results suggest that there is a need to reassess the existing education system in order to provide more opportunities for engineering students to study subjects that relate to the environment and to learn more about issues related to sustainability and sustainable development and how they relate to regional and local environments.

Q2. *If YES, how do you rank sustainable development and environmental engineering education in terms of your engineering training and education?*

	South Africa	%	Australia	%
Very Important	32	44.4	15	40.5
Important	35	48.6	20	54.1
Of Little Importance	5	7.0	2	5.4
Total	72	100	37	100

Again, from the results it is obvious that students regard sustainable development and environmental engineering education to be a crucial element of their engineering education and training.

Q3. *Does your undergraduate degree provide any education/training in sustainable development and environmental engineering education?*

	South Africa	%	Australia	%
YES	9	12.5	13	35.1
NO	63	87.5	24	64.9
TOTAL	72	100.0	37	100.0

From the information provided by the students, especially from those in South Africa, there seems to be an insufficient quantity of material provided in the basic engineering degree programme. Also, it has been found that the curricula currently do not meet the demands and expectations of the surveyed students.

It should be mentioned at this point that the ECOSA questionnaire also indicated a shortage of environmental education material in schools. Formal schooling appears to be characterised by inadequate resources in all areas, including policy formulation, teacher training and teaching material [7].

It has been found that the curricula in Australia is responding to the need for more education on the environment, although the situation could be improved.

Q4. *If YES, what sort of education and training in sustainable development and environmental engineering education is offered in your undergraduate degree programme?*

Those students who responded in the affirmative to Question 3 offered some comments on the content and nature of education and training programmes relating to the field.

South African points of view:

- A subject on Design Project II provides students with knowledge on how to design a project that can be marketed for future use.
- Training and education are provided on the application of engineering solutions using modern technology, operation process of industry and on the general awareness of the environment through regular visits to chemical/industrial plants.

Australian points of view:

- Lectures on sustainable development.
- Some elective subjects offered in 2nd year.
- One core subject offered in 4th year.
- Issues concerning the environment and some background to the control, monitoring and modelling of pollution.
- Issues on renewable energy resources.
- Issues in electrical safety (eg effects of transmission powerlines).
- Alternative energy systems (eg biomass, solar).
- Effects of pollution have been discussed and ways in which pollution can be reduced have been taken into consideration during the course at various stages.
- A subject on environmental engineering was introduced in 4th year to chemical engineering.
- Issues in energy conservation.
- An awareness of the impact on the environment due to engineering projects is promoted in the programme. We are made conscious of how our decisions affect the environment.
- Issues of pollution and various emission gases.

Although the results show that there is better coverage of the issues in the engineering curriculum in Australia compared to South Africa, students from Australia have commented that those issues were not covered in great detail.

Q5. *If NO, should your undergraduate degree programme offer education and training in sustainable development and environmental engineering education?*

	South Africa	%	Australia	%
YES	53	84.1	20	83.3
NO	10	15..9	4	16.7
TOTAL	63	100.0	24	100.0

Students from both regions indicated their strong support for the establishment of education and training on the environment and sustainable development in their undergraduate engineering degree programmes.

Q6. *If YES, what sort of education and training should your undergraduate degree programme be offering in sustainable development and environmental engineering education?*

The responses to this particular question ranged from general to more specific comments and ideas. Some of the more general comments included the following:

- Awareness of global environmental problems.
- Offering courses that deal directly with the overall environment and how to solve environmental problems.
- Issues of environmental pollution and ways to prevent it.
- Integrating key environmental problems/issues within engineering courses.

Other students advocated the following specific topics:

- Sustainable development/Environmental engineering, with specific emphasis on:
  - Providing workshops and tutorials on the importance of sustainable development and to practise this in engineering.
  - Subjects on environmental engineering and integrating this in general engineering.
  - The ability to develop sustainable development projects.
- Energy issues, with a focus on:
  - More subjects on renewable energy, eg solar energy.
  - Efficient use of resources.
- Technology/design issues, such as:
  - Application of environmentally-friendly technology to minimise harm to the environment.
  - Better engineering designs.
  - More emphasis on energy-efficient design.
  - Awareness of different environmental problems.

  - Knowledge of the impact of engineering technology on the environment and of solutions.
  - More chemical/industrial visits to get a better appreciation of engineering equipment and technology used.
- Engineering practice/processes, which includes:
  - Impact of engineering systems/practices on the environment.
  - Understanding the impact on the environment of waste generated from engineering processes.
  - Re-engineering procedures to consider the environment.
- Waste /recycling issues, including:
  - Handling of by-products and waste minimisation in engineering.
  - Recycling and reuse of materials used in engineering.
  - Handling of radioactive materials and how to safely dispose of the waste-material.
  - Waste management, recycling and handling of hazardous materials.
- Management issues, such as:
  - Project, environment and human resources management issues.
  - How effectively to manage/run a plant.

Other students opted for more education and training on issues such as the greenhouse problem and ozone layer protection.

Some students requested exposure to less common but interesting programmes. For instance, courses that allow students to be able to predict or assess the status of the environment in the future, environmental protection laws and environmental economics issues.

Q7. *Which global problems/issues do you see are an area of concern within your studies with respect to sustainable development and environmental engineering education?*

1	Population	7	Water quality/pollution
2	Air quality/pollution	8	Land issues
3	Hazardous materials	9	Endangered species
4	Waste min./recycling	10	Human ecology
5	Use of non-renew. Res.	11	Others
6	Use of renewable res.		

The students have shown similar patterns of interest and concern with global issues, with the exception of issues on energy (Figure 1). However, African students have a primary interest in the air environment (air quality/pollution) and issues of hazardous material. Perhaps this reflects problems in the local environment?

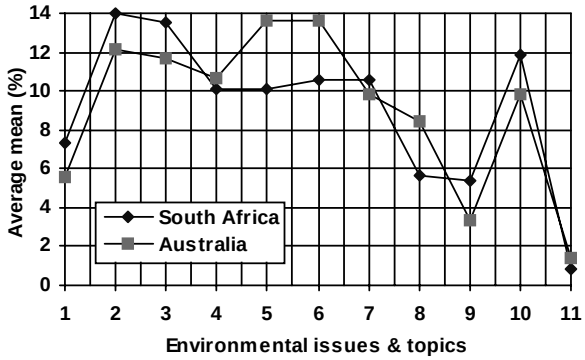

Figure 1: The importance of global issues and topics.

Q8. *In which Engineering disciplines do you think sustainable development and environmental engineering education topics should be included?*

	South Africa	%	Australia	%
Ranked	33	45.8	20	54.0
Not Ranked	36	50.0	17	46.0
No Response	3	4.2	0	0.0
Total	72	100.0	37	100.0

The results show that the field of sustainable development and environmental engineering is particularly relevant to industrial, chemical and civil engineering, although they would like the other engineering disciplines to be at least familiar with the general issues and to take part in protecting and saving the environment.

The majority of students from South Africa who responded to this question indicated that the issue of sustainable development and environmental engineering is more relevant to the field of industrial and chemical engineering. Most Australian students agreed with South African students, but indicated civil engineering instead of industrial engineering (Figure 2).

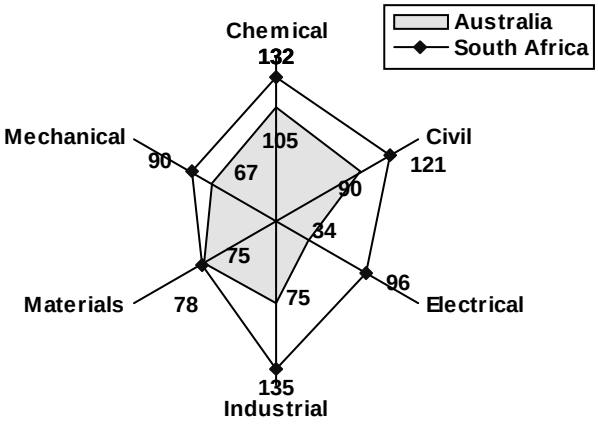

Figure 2: A radar diagram indicating students' rating of engineering disciplines according to the need for the inclusion of sustainable development and environmental engineering issues and topics.

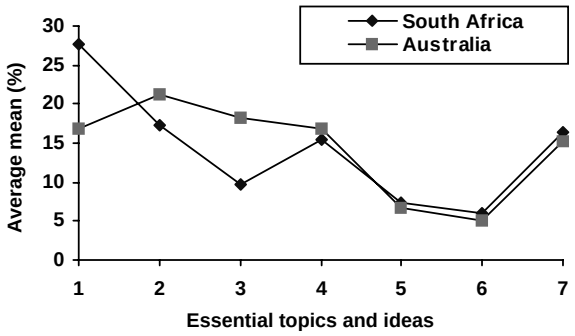

Figure 3: A line graph showing the importance of the essential issues and concerns.

Q9. *What do you consider to be the essential topics and ideas on sustainable development and environmental engineering education that should be included in engineering curricula?*

The table below shows the numbers corresponding to the essential topics and ideas.

1	Environmental protection	5	Human resources management
2	Environmental management	6	Capital resources management
3	Resource management	7	Consumption of natural resources
4	Alternative energy resources		

A mean score was taken to determine what students consider to be the essential topics and ideas on sustainable development and environmental engineering. As shown in Figure 3, there are differences in opinions on environmental protection and resource management. South African students are more interested in protecting the environment, whereas Australian students are more concerned with managing the environment.

Q10. *Please rank in order of importance, from 1 (least) to 5 (most), how you would prefer the Faculty/Department to offer sustainable development and environmental engineering education courses:*

	RANKING *1(least) - 5 (most) important*	
ENGINEERING COURSES	SOUTH AFRICA	AUSTRALIA
Undergraduate programmes	185	136
Postgraduate programmes	154	117
Continuing education programmes	179	108
Open-learning & distance education	168	54
Short courses	169	126

From the table it is clear that African students do not have any special preference for the type of education where issues of the environment and sustainable development are treated. Undergraduate engineering degree programmes have obtained the highest score of preference by Australian students.

Q11. *Please rank in order of importance, from 1 (least) to 2 (most), how you prefer the Faculty/Department to offer such education/ training courses:*

	RANKING *1(least) - 2(most) important*	
ENGINEERING COURSES	SOUTH AFRICA	AUSTRALIA
Part-time courses	68	16
Full-time courses	62	19
No response	1	2

Students from Africa are keen to have such courses delivered on a part-time basis, and students from Australia indicated that they prefer to have the courses done on a full-time basis.

CONCLUDING REMARKS

The results of this pilot study demonstrate that students consider the area of environmental education and the principle of sustainable development to be important and that they should be included in engineering education curricula. This answers the first question as to whether engineers need to be environmentally educated.

The other question was whether these issues are currently being met in engineering curricula. From the data gathered, the situation in Australia is progressively improving, although there are still problems with application in general engineering disciplines. The situation in the Republic of South Africa is quite different. The impression that one may get from students' responses is that there is insufficient or no coverage of issues and topics on the environment and sustainable development in engineering education in South Africa. Based on this, one may conclude that there are problems with the existing engineering curricula in South Africa and that they need to be resolved as a matter of urgency.

It is evident that future engineers must be exposed to, and must learn how to think along the line that, sustainable and ecologically sound engineering is the only option available in creating a sustainable world for all humankind, preventing further degradation of the environment.

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BIOGRAPHIES

Duyen Q. Nguyen graduated with a Bachelor of Applied Science, majoring in chemistry and environmental management from Deakin University, Australia, in 1994. Since December 1995 she has been with the UNESCO International Centre for Engineering Education (UICEE) in the Faculty of Engineering at Monash University, Melbourne, Australia, currently as a postgraduate student and part-time project officer. Her special research interests are in environmental engineering education, sustainable development and curriculum development.

She was awarded a UICEE Women in Engineering Education Scholarship in 1997, enabling her to pursue her studies for the degree of Master of Engineering Science by research, in conjunction with the Department of Mechanical Engineering at Monash University. She has also served on several national and international engineering education conference organising committees.

Duyen has already published in journals and presented a number of conference papers in the field of environmental engineering education. In 1998 she was awarded a UICEE Silver Badge of Honour for her contribution to engineering education and to the operation of the Centre. She was jointly awarded a UICEE Diamond Award (first place) for a distinguished contribution in delivering an outstanding paper to the *Global Congress on Engineering Education* in 1998.

Zenon Jan Pudlowski graduated Master of Electrical Engineering from the Academy of Mining and Metallurgy (Cracow, Poland), and Doctor of Philosophy from Jagiellonian University (Cracow), in 1968 and 1979 respectively.

From 1969 to 1976 he was a lecturer in the Institute of Technology within the University of Pedagogy (Cracow). Between 1976 and 1979 he was a researcher at the Institute of Vocational Education (Warsaw) and from 1979 to 1981 was an Adjunct Professor at the Institute of Pedogogy within Jagiellonian University. From 1981 to 1993 he was with the Department of Electrical Engineering at The University of Sydney, where, in recent years, he was a Senior Lecturer.

He is presently an Associate Professor and Director of the UNESCO International Centre for Engineering Education (UICEE) in the Faculty of Engineering at Monash University, Clayton, Melbourne, Australia. He was Associate Dean (Engineering Education) of the Faculty of Engineering between 1994 and 1998.

In 1992 he was instrumental in establishing an International Faculty of Engineering at the Technical University of Lodz, Poland, of which he is the Foundation Dean and Professor (*in absentia*). He was also appointed Honorary Dean of the English Engineering Faculty at the Donetsk State Technical University

(DonSTU) in the Ukraine in 1995.

His research interests include circuit analysis, electrical machines and apparatus, implementation of computer technology in electrical engineering, software engineering, methodology of engineering education and industrial training, educational psychology and measurement, as well as human aspects of communication in engineering. His achievements to date have been published in books and manuals and in over 200 scientific papers, in refereed journals and conference proceedings.

Professor Pudlowski is a Fellow of the Institution of Engineers, Australia. He is a member of the editorial advisory boards of many international journals, including the *International Journal of Engineering Education*, the *International Journal of Electrical Engineering Education* and the *European Journal of Engineering Education*. He is the founder of the Australasian Association for Engineering Education (AAEE) and the *Australasian Journal of Engineering Education* (AJEE), and was the 1st Vice-President and Executive Director of the AAEE and the Editor-in-Chief of the AJEE since its inception in 1989 until 1997. Currently he is the Editor-in-Chief of the *Global Journal of Engineering Education*. He is the Foundation Secretary of the International Liaison Group for Engineering Education (ILG-EE).

Professor Pudlowski is a member of the UNESCO International Committee on Engineering Education (ICEE). He has chaired and organised several international conferences and meetings. He was the Academic Convener of the *2nd World Conference on Engineering Education*, the General Chairman of the *1st, 2nd and 3rd East-West Congresses on Engineering Education* and General Chairman of the *UNESCO 1995 International Congress of Engineering Deans and Industry Leaders*.

He received the inaugural AAEE Medal for Distinguished Contributions to Engineering Education (Australasia) in 1991 and was awarded the Order of the Egyptian Syndicate of Engineers for Contributions to the Development of Engineering Education on both National and International Levels in 1994.

In June 1996 Professor Pudlowski received an honorary doctorate from the Donetsk State Technical University in the Ukraine in recognition of his contributions to international engineering education, and in July 1998 he was awarded an honorary Doctorate of Technology from Glasgow Caledonian University, Glasgow, Scotland, United Kingdom. In 1997 he was elected a member of the Ukrainian Academy of Engineering Sciences.

APPENDIX

Table 2: Listing of major environmental conferences and events.

Major Environmental Conferences	Place/Year	Concerning issues
United Nations Conference on the Human Environment (UNCHE)	Stockholm, Sweden 1972	• Protect and improve the human environment
United Nations World Population Conference (UNWPC)	Bucharest, Romania 1974	• Population policies • Human welfare and development
United Conference on Human Settlements (UNCHS)	Vancouver, Canada 1976	• Shortages of housing • Crises of urban and rural communities • Proper usage of land • Access to clean water • Improving living conditions
United Nations Conference on Desertification (UNCOD)	Nairobi, Kenya 1977	• Desertification
United Nations Water Conference (UNWC)	Mar del Plata, Argentina 1977	• Water management • Water consumption/ usage
2nd United Nations Conference on the Human Environment	Nairobi, Kenya 1982	• Review the progress of UNCHE
2nd United Nations World Population Conference	Mexico City, Mexico 1984	• Review the progress of UNWPC
United Nations Conference on Environment & Development (UNCED)	Rio de Janeiro, Brazil 1992	• Environment and Development issues
United Nations Conference on Water and Environment (UNCWE)	Dublin, Ireland 1992	• Review the progress of UNWC • Ensure quality restoration of all streams, lakes, rivers.
United Nations Conference on Population and Development (UNPD)	Cairo, Egypt 1994	• Population growth • Family planning services • Sex education • Safe abortion • Improving the status of women
2nd United Conference on Human Settlements (UNCHS)	Istanbul, Turkey 1996	• Review the progress of the 1st UNCHS Conference