GREEN STRENGTH SUSTAINABILITY: A CASE STUDY OF CHEMICAL ENGINEERING STUDENTS

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Abstract

Green chemistry is a relatively new area of science and technology aimed at improving chemical processes and thereby avoiding negative impacts on human health, safety, and the environment (EHS). It is based on careful selection of raw materials for the production of various products, excluding the use of hazardous substances. The field of green chemistry has received much attention from the scientific and industrial communities in almost every highly industrialized nation. It is understandable that the principles of green chemistry should generate strong interest in countries or regions with high production capacities. Unfortunately, that industry resulted in a number of highly contaminated sites, hazardous and resource consuming production tools. A strong industrial development in European Union (EU) countries took place in last two decades focused on a profit, when there was small or no concern about some specific environmental issues. Human health and safety was rather controlled with robust standards. Environmental, health and safety protection remain a major component of co-operative activities between EU and other world. In particular, management of environmental risks associated with man-made changes, industrial, agricultural and military wastes, including risks for soil, water, air and the food chain and possible remediation are identified as one of the three priorities of the EU "Specific measures in support of international co-operation" program. These are challenges that need to be faced worldwide. With that respect, Green Chemistry is a promising approach to pollution prevention because it applies innovative scientific solutions to real world environmental situations. Green sustainability has started from educational and training institutions on entire vertical of education. In our research, we investigated chemical engineering freshman and senior students considering their perception toward importance of EHS area and about self-reported level of green competencies achievement during study. Freshman and senior students of chemical engineering estimated importance of green competencies as highly desirable. Existing curriculum in chemical engineering allows students achievements at basic level, while for high level of green chemistry; curriculum upgrade / modification is needed. It was judged that proposed green chemistry courses show potential for implementation and use at competitive higher education and training.

Keywords: chemical engineering, green abilities, environmental health and safety, sustainability

Introduction

Green chemistry formed as an area of research in the late 1990s. Over the past 15-20 years, it has become a leading scientific paradigm underlying the development of modern industrial production [1]. The corresponding technologies, processes, and products are introduced not only in the chemical industry but also in other industries that use chemicals, for example, in the agricultural, textile and food industries. Companies such as Armani, Adidas, Nike, Puma, and Levi Strauss & Co. can serve as an example of the use of the principles of green chemistry in the production of clothing. They have all pledged to lead the industry to zero discharge of hazardous chemicals by 2020 [2]. Despite a significant growth in the rates of introduction of green chemical technologies and products in last decade, this trend is regarded as not enough developed in EU countries industry.

In 2013 the European Federation of Chemical Engineering celebrated sixty years of the chemical industry development and establishment of the corresponding academic discipline in the Universities and University Departments closely related to that industry. The last sixty years have seen enormous developments in the chemical industry and the discipline of chemical engineering and it is obvious that Europe has had an important role to play in these developments.

Chemical engineering, as an academic discipline, involves the design and management of biological, chemical and physical processes that enable raw materials to be converted into valuable products. It is a discipline that is based on scientific knowledge from chemistry, physics, biology and mathematics combined with engineering principles. Chemical engineers design both products and the processes and manage their operation and optimization in order to ensure safe, that they are economically viable and environmentally acceptable. On the other hand, the processes that are managed, as a part of the designed plant, include biological and / or chemical reactions in a sequence that provides minimal loss of materials and consumption of energy. The same unit operations are equally applicable across industries such as petroleum / petrochemical industry, food processing, mining and related industries, production of plastics and chemicals, pharmaceuticals production, environmental management, and biotechnology where, in some cases, additional skills of the chemical engineer are needed. It is important to note that Chemical Engineers must be capable of reacting to any change in production conditions and partly because the Chemical Engineering is closely related to discoveries in the enabling sciences of the profession such as biology, chemistry, biochemistry, microbiology and physics. Hence, the chemical engineer must be familiar with the language and principles of these sciences (at least to acquire additional specific skills) and / or to be able to work closely with specialists from these fields and other fields of engineering, management and industrial relations.

Therefore, training of specialists who would have a responsible attitude to the country is a focal issue for EU. If today's students and postgraduates - chemists, chemical engineers - deeply realize that we do not and will never have another Earth, if they get to know the existing opportunities and already implemented developments in green chemistry, there is hope that they will further evolve this area of science and consecutively strive for minimization of environmental, health and safety damage from operation of industrial enterprises. Hence, there would be a chance that our next generations will live under tolerable life conditions and be relatively healthy.

Against this background, the questions explored in our study are:

1. Does a new synthesized area of green competences, entitled Environmental, health and safety, enhance students' motivation toward perspectives of green jobs?
2. What is the perceived and self-assessed current level of green competences?

Green Chemistry and Jobs

The chemicals industry and other related industries supply us with a huge variety of essential products to everyday living. However, these industries have the potential to seriously damage our environment. In the last decade, the scientific community has witnessed a growing interest in environmental issues and the value of environmentally friendly energy generation and chemical processes. The combination of chemical engineering tools with the findings of green chemists, biologists, and environmental scientists has allowed the design of new processes for the manufacture of chemicals, fuels, and products with a much reduced environmental footprint. Furthermore, the developed environmentally benign alternative technologies of green chemistry have been proven to be economically superior and function as well as or better than more toxic traditional options [3].

Green Chemistry can be defined as the "design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances" and illustrates the 12 principles of Green Chemistry, a set of “design rules” which illustrate that field, announced by Anastas and Warner [4]:

1. **Prevention:** It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom economy:** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. **Less hazardous chemical syntheses:** Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing safer chemicals:** Chemical products should be designed to affect their desired function while minimizing their toxicity.
5. **Safer solvents and auxiliaries:** The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. **Design for energy efficiency:** Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. **Use of renewable feedstock:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce derivatives:** Unnecessary derivatisation (use of blocking groups, protection / deprotection, and temporary modification of physical / chemical

processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for degradation:** Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. **Real-time analysis for pollution prevention:** Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently safer chemistry for accident prevention:** Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

The challenge of green chemistry for both academics and industrialists is to devise sustainable strategies that meet the demand for chemical products from an ever-increasing population. Green chemistry addresses the following aspects of manufacturing [5]:

1. Working through the arc of an industrial process, the first challenge is to identify renewable feed stocks. The current front-runners are non-food plants, in which case chemists must find effective ways of converting the whole plant into useful products.
2. The reactions involved in making chemical products must be devised to minimize environmental impact. For example, many raditional catalysts are based on metals, which can be toxic or scarce; nonmetallic catalysts must therefore be developed, perhaps based on organic compounds (organocatalysts) or on enzymes that have been modified to perform useful reactions.
3. Engineering is also crucial - industrial processes and reactors must be designed to maximize efficiency and reduce waste. Improved analytical techniques are necessary to monitor the fate of potentially harmful chemicals in reactions and in the environment.

4. The impact of chemicals on the environment can be reduced by finding replacements with reduced toxicity and increased biodegradability compared with existing mass-produced compounds.

Talking about green principles and bearing in mind the "engineering" part of Chemical Engineering, it would be of great importance to present the 12 Principles of Green Engineering elaborated by Anastas and Zimmerman [6]:

1. **Inherent Rather Than Circumstantial:** Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently non-hazardous as possible.
2. **Prevention Instead of Treatment:** It is better to prevent waste than to treat or clean up waste after it is formed.
3. **Design for Separation:** Separation and purification operations should be designed to minimize energy consumption and materials use.
4. **Maximize Efficiency:** Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. **Output-Pulled Versus Input-Pushed:** Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
6. **Conserve Complexity:** Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. **Durability Rather Than Immortality:** Targeted durability, not immortality, should be a design goal.
8. **Meet Need, Minimize Excess:** Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
9. **Minimize Material Diversity:** Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. **Integrate Material and Energy Flows:** Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.

11. **Design for Commercial "Afterlife":** Products, processes, and systems should be designed for performance in a commercial "afterlife."
12. **Renewable Rather Than Depleting:** Material and energy inputs should be renewable rather than depleting.

Chemical Engineers will play an essential role as designers and managers of hundreds of different products, processes and production systems which are currently or might be in the future the base of the welfare state. Green Engineering aims at transforming traditional Chemical Engineering practices into a more practices. Green Engineering feeds on a wide variety of disciplines and theories, it is of crucial importance to identify the needs for an specific applying the correct approach to the general design philosophy, to safety, to the chemistry, to the product and to the process and to the auxiliary facilities. The continuous adaptation of green engineering is the very base of sustainability in the chemical and process industry and that is the main reason to feed on all these disciplines argued by [7]. Principles of green engineering cannot be static, because environment, society and economy are dynamic. Therefore, Chemical Engineers are called to identify, assimilate and study the way in which these disciplines can be included within the design criteria to achieve sustainable solutions [7].

Finally, it must be highlighted that education and training in green engineering is the key weapon to tackle the current needs. Green engineering has to be introduced at academic and industrial levels to create a critical mass of engineers and scientists to undertake this challenge as soon as possible [7].

It is clear that Green Engineering is the development and commercialization of industrial processes that are economically feasible and reduce the risk to human health and the environment. All the above principles should be taken into account when determining the details of the project STRENGTH Competences Matrix.

Environmental health and safety area courses development

The green transition will require the development of a better understanding of the implications of green jobs on health and safety at the workplace. On the one hand, measures aimed at environmentally friendly workplaces can help to improve working environments, having a positive impact on workers' safety and health. In order to shape the future of occupational safety and health in green jobs and inform EU decision makers, Member States' Governments, trade unions and employers, the European Agency for Safety and Health at work carried out research about the new and emerging risks associated with green technologies by 2020. Considering this research, the Leonardo da VINCI TOI Project STRENGTH (Structuring of Work Related Competences in Chemical Engineering), 2013-1-ES1-LEO05-66726, developed green matrix of key green competencies areas for chemical engineering, namely: agriculture; biotechnology; environmental, health and safety; food science, and pharmacy.

As the most important area, the environmental, health and safety (EHS), was detected. Several health and safety aspects were detected which could decrease green economy benefits and scale: a) Potential for exposure to unknown hazards from new processes and materials, b) Substitution of chemicals for environmental reasons could result in greater risks to workers, c) Chemicals obtained from renewable sources can still be toxic, and d) Potential risks at the recycling stage.

Environmental Health and Safety considers environmental protection, occupational health and safety. Its general objectives comprise prevention of incidents or accidents that might result from abnormal operating conditions at manufacturing facilities on the one hand, and reduction of adverse effects on the environment and human health that result from normal operating conditions on the other hand [8]. Its core value is to improve safety and health at work place, to support the continuous education and training of employers and employees in a defined area of economic activity, and to work cooperatively with regulating authorities to ensure the safety and health for all workers and for the environment [9].

The research mission of this branch is to provide fundamental information regarding actions on several major topic areas: Risk management & insurance, Fire & life safety, Physical safety, Chemical safety, Biological safety, Radiation safety, Ergonomics, Hazardous waste management, Environmental protection, Emergency response, Indoor air quality, Security for safety professionals, Occupational health programs, Communicating through the mass media. Most of the issues listed above are typically multi-faceted, thus commonly their research areas are overlapping. Nevertheless, their common goal is to characterize the interface between human health and environment through a set of tools and methods that identify, quantify and / or categorize exposure and thus to prevent, and control factors that can damage both human health and the environment [10].

EHS raises fundamental awareness in Chemical Engineers and ability to adequately handle specific inquiries and problems. This means to develop, plan, implement and review activities to achieve end-user satisfaction, zero accident, safe workplace and business sustainability employing Chemical-Engineering-based knowledge. Environmental, Health and Safe postgraduate programmes are designed to provide a broad theoretical and practical education for Chemical Engineers who desire green profile positions in academic, industrial or government laboratories with an emphasis on managing environmental impacts and Health & Safety. The programmes are designed for those who are seeking to update their current knowledge adopting green skills and to enhance their career opportunities in specific areas such as occupational safety and health, environmental management, fire safety, food safety the built environment and risk management. Advanced professional education for those Chemical Engineers who desire leadership positions in EHS practice, policy analysis, professional communication, programme management, high-level administration, and / or decision-making in an environmental health and safety setting is offered by the Master and PhD programmes in this occupational field.

Professional realization is anticipated within occupations like Environmental, Health & Safety Specialist; Environmental Health & Safety Manager; like Environmental, Health & Safety Coordinator; health and safety analyst, Health and Safety consultant. Employment is expected as well within manufacturing, technology, public and private sectors, chemical, environmental and associated industries in a variety of health, hygiene, safety, fire, food, quality, regulatory, consultancy and related roles [11].

By mapping existing competencies in industry, STRENGTH developed 10 courses in EHS area aimed for vocational education and training at national and international level using mobility scheme procedures. Courses allow systematically development of three main cognitive components: knowledge, skills and wider competences of critical thinking and decision-making by considering the European qualification framework (EQF) [12], and credits system (ECVET) [13] for vocational education and training at EQF level 6 and 7. All ten courses comprise together of 34 European Credits (EC) and allow achievements described with 19 competences for knowledge component, and 14 skill competencies which are condensed in 8 green abilities. All cognitive structures could be obtained both at level 6 and 7 of EQF.

Project STRENGTH matrix area of EHS consists of the following courses:

1. BIOSAFETY. This course provides information about protection of laboratory workers, the environment, and the community from exposure to bio-hazardous materials while protecting the integrity of experimental material. It presents the rules to perform research involving biological agents in a safe and responsible manner, and in compliance with applicable regulations and policies. This course gives as well the basis for the application of combinations of laboratory practice and procedure, laboratory facilities, and safety equipment when working with potentially infectious microorganisms to minimize the risk of transmission of disease and / or release to the environment (3 EC).

2. CHEMICAL SAFETY. The course covers the main topics in safe handling of chemicals in the lab. It provides resources on how to monitor that all unwanted chemicals are disposed of in an environmentally friendly manner and in compliance with national / international environmental regulations; how to communicate the potential hazards which are present when handling hazardous chemicals and to describe the proper methods of collecting Hazardous (Chemical) Waste, thus reducing the number of chemically related occupational illnesses and injuries, and protecting the environment (3 EC).

3. EMPLOYEE / OCCUPATIONAL SAFETY. The course presents information about providing a safe working environmental for all reducing risks to the personnel with emphasis on personal responsibility and environmentally sound management. It describes the importance of using safe work practices while carrying out the responsibilities of employees' jobs. It stresses as well on the management's primary responsibility for ensuring a safe working environment (4 EC).

4. FIRE SAFETY. The overall goal of the course is to present information about all aspects of fire safety, namely the protection of life and property from fire. It aims to identify and minimize those conditions and / or actions that may encourage fires to start and spread. Trainees are educated on fire safe practices, on how to conduct fire safety inspections, to prepare and implement evacuation plans; to maintain a database of fire safety compliance and incident information (3 EC).

5. LABORATORY SAFETY & HAZARDOUS WASTE. This course covers all current regulatory issues regarding proper chemical handling procedures, including

requests for chemical pickup, labelling and signage, how to clean out a lab, and how to handle a hazard emergency. It also presents key elements of a Chemical Hygiene Plan and laboratory safety. Special emphasis is paid to the so called Controlled Substances - drugs or substances controlled for research use only, and the legislative basis for their exploitation. The course provides essential information specifically for those working in medical, biological and life sciences research laboratories that contain hazardous biological materials. It is designed to ensure compliance with the regulatory requirements applicable to those laboratory research activities (4 EC).

6. INDUSTRIAL HYGIENE. The course is focused on provision of expertise and advisory services for assessing the daily hazards encountered in the work place and the research laboratory. It describes the development of procedures and controls (engineering controls and personal protective equipment) that minimize the adverse impact of working with hazardous substances. It also postulates the principles of determining the nature and amount of exposure and compare this information to Occupational Safety and Health regulatory limits and recommended standards (4 EC).

7. RADIATION SAFETY. Radiation Safety course includes an introduction to the science and technology of ionizing radiation in terms of: sources, fundamentals of measurement, bioeffects, regulations, Good work practices, and accident recovery. It also discusses topics related to control of radioactive materials and radiation producing devices is consistency with national / international regulations and recommendations (3 EC).

8. GENERAL SAFETY, INJURY PREVENTION & EMERGENCY PREPAREDNESS. The course covers practices and procedures for preventing employee injury or illness from potential workplace hazards. Information is provided on emergency kits, family preparedness plans, fire safety, earthquake preparedness and more (3 EC).

9. LABORATORY AUDIT PROGRAM. The course describes the basic steps in conducting safety audits of laboratories in terms of providing people with a safe working environment and encouraging them to operate in an environmentally friendly manner. The course is designed to provide information and tools necessary to conduct a research safely, to protect the environment, and to meet regulatory requirements (3 EC).

10. GLOBAL ENVIRONMENTAL MANAGEMENT SYSTEM: ISO 14001 STANDARD. The course presents the fundamentals of the voluntary international standard ISO 14001 as a tool establishing the requirements for an environmental management system (EMS). The main objective of the standard: organization to establish an EMS that is integrated with the overall business management process is explained. The basic elements of the EMS - Environmental Policy, Planning, Implementation and Operation, Checking, and Management Review are discussed. The concept of continual improvement of the EMS (such as improved communications and employee awareness, improved environmental performance, and improved emergency planning and response programs) as an integral part to the standard evolution is introduced (3 EC).

Methodology

Importance of green competences and skills was assessed by surveying chemical engineering freshman students and their senior-level counterparts. Beside this, students' achievements in chemical engineering were contrasted with their self-assessment of green competencies obtained during the study.

Sample

The sample for study was drawn from chemical engineering students at Cracow University of Technology, Cracow, Poland. Group of freshman engineering students consists of 30 students while the senior-level counterparts were of 31 students. The university recruited in this study was selected by role models (university scientist, applied science researchers, or young researchers) in order to explore of possibilities of project STRENGTH results exploitation. Groups of students recruited in this study had similar demographic in gender, but different in age. Paper and pencil survey was distributed accordingly. The participants' genders were not evenly distributed: 72.1% (nF = 44) females and 27.9% (nM = 17) males. Freshman students were aged 19 ± 1 year while seniors were aged 23 ± 1 year.

Instrument

Student experiences, and perceived competence importance were considered important for the long-term success of STRENGTH courses. For this purpose, a researcher-developed questionnaire addressing the specifics of the course offerings was administered to the students. The survey items were validated by an expert panel.

The expert content validators were university professors and chemical engineering experts. An expert panel provided evidence of survey content validity. The survey consists of the 41-item survey divided into three subscales. The knowledge subscale was surveyed with nineteen items, the subscale of skills with fourteen, and green abilities with eight items. For the assessment, a 6-point phrase completion scale was used as recommended by Hodge and Gillespie [14]. The scale intervals form a continuous type from minimum (0) to maximum (5). The scale does not present the mean, but ensures the comparability of continuous responses and produces better assumptions of parametric statistics while avoiding bias [14].

Procedure and data analysis

The survey is designed to assess general attitude toward green competencies. The data is collected in Cracow when students attended residential workshops in January 2015. Students were instructed to read the competences, try to think about what they generally feel about the Importance of competence, and also circle the number (0-5) that best represents their current green knowledge, skills and abilities (Current level). Procedure took about 10-15 minutes to complete the survey. Students were warned that do not spend too much time on any item and indicate their immediate feeling and move on to the next item. High response rate was obtained by direct presence of lecturers / instructors and survey administration.

Data analysis was conducted using SPSS 22. Descriptive analyses were conducted to present the student basic information, the mean score of predictor variable, and of student self-assesed level of competence mastering. Cronbach alpha as a measure of internal consistency was calculated for entire survey, and at its subscales. The Levene's test for equality of variances was used. A Multivariate analysis was conducted to find and confirm significant relationships between groups with an effect size. The measure of the effect size is eta squared.

Results

Reliability

Internal consistency coefficients (Cronbach alpha) for two main green readiness scales and their subscales are presented in Table 1.

Table 1. Internal consistency of green readiness scales (n=61)

Scale	Knowledge	Skills	Green abilities	Total
Importance	0.86	0.91	0.85	0.94
Current level	0.91	0.95	0.87	0.96

As shown, the alphas across the scales ranged between values of 0.85 to 0.96. Cronbach's alpha scores above 0.9 are considered as strongly reliable and highly adequate for research applications [15].

Descriptive statistics and variance analysis

The Levene's test confirmed that the study sample did not violate the assumption of normality, which confirmed that the sample is normally distributed ($p>.05$).

Multivariate analysis of variance revealed significant difference in perception of green knowledge importance. Both groups had estimated importance of green knowledge as high, nevertheless, seniors prevailed at item of KN5, KN6, KN18 ($p<0.05$) with moderate effect size (eta squared = 0.1). Self-assesed green knowledge is significantly higher at seniors at almost all items. Effect size is regarded as high (eta squared>0.14) [15].

The means and SDs for each of the survey item according to the survey subscales are presented in Table 2 and 3.

Table 2. Descriptives of knowledge competences' importance and self-assesed current level of freshmen and senior students

Knowledge (KN)		Importance				Current level			
		Fresh.		Senior		Fresh.		Senior	
		M	SD	M	SD	M	SD	M	SD
KN1	Apply fundamentals of chemical composition, structure, and properties of substances	3.9	0.8	4.1	0.8	3.3.	0.9	3.9	1.1
KN2	Use basic rules of calculus and statistics	3.3	1	3.8	1.2	2.8	0.8	3.5	0.9
KN3	Describe data related with plant and animal organisms, their tissues and cells	3.3	0.9	3.4	1.3	3.2	0.9	3.3	0.9
KN4	Apply engineering science and technology practical principles	4	0.8	4.2	1	2.3	0.9	3.7	0.8
KN5	Differentiate sources of pollution and determine their effects on the	3.8	1	4.5	0.8	2.8	1.1	3.9	0.9

	environment								
KN6	Define hazardous communication and hazardous waste operations	3.9	0.9	4.4	0.9	2.2	0.9	3.6	0.9
KN7	Advise on environmental, safety and industrial hygiene regulatory requirements and best practices; lead job hazard evaluations and industrial hygiene surveys to assess employee health and safety risks and develop and implement appropriate improvement plans	3.6	0.8	3.9	0.8	1.9	1.3	3.2	1.2
KN8	Evaluate and manage environmental, social and health impacts.	3.8	0.8	3.9	0.9	2.7	1.1	3.3	1
KN9	Maintain an in-depth knowledge of applicable regulatory requirements	3.7	1	3.1	1.3	2	1.3	2.4	1.3
KN10	Enforce environmental, health and safety standards	4.1	0.8	3.9	1.2	2.4	1.1	2.8	1.2
KN11	Perform emergency / crisis management in terms of planning and response, including incident investigation to ensure thorough root-cause analysis and comprehensive corrective action	4.3	0.7	4.0	1.1	2.5	1.3	2.9	1.1
KN12	Anticipate, identify and evaluate hazardous conditions and practices	4.1	0.7	4.3	0.9	2.7	0.9	3.3	1.1
KN13	Develop hazard control designs, methods, procedures and programs; implement and maintain plant-level EHS regulatory compliance and training programs	3.5	0.9	3.4	1.3	1.8	1.1	2.7	1.1
KN14	Implement, administer and advise others on hazard control programs	3.3	0.9	3.4	1.2	1.5	1.1	2.2	1.4
KN15	Draft a future safety plan and statement based on real time experiences and facts	3.8	0.8	3.7	1.3	1.8	1.3	2.4	1.4
KN16	Develop, implement and lead best-practice safety and environmental programs to drive pollution prevention, risk prevention and continuous improvement	4.1	0.9	3.6	1.2	2.1	1.1	2.6	1.3
KN17	Maintain EHS Management Systems, including ISO 14001 registration	3.1	1	3.4	1.3	0.9	0.8	2.0	1.8
KN18	Administer Process Safety Management (PSM) and Risk Management Planning (RMP)	2.7	0.8	3.1	1.1	1.1	1.1	1.8	1.3

	programs, including Process Hazard Analysis, Pre-startup Safety Review and Management of Change								
KN19	Coordinate permitting of manufacturing processes and manage follow-up permit compliance	3.6	0.9	3.5	0.9	1.2	0.9	2.3	1.4

Table 3. Descriptives of skills' and green abilities importance and self-assesed current level.

Skills (SK)		Importance (%)				Current level (%)			
		Fresh.		Senior		Fresh.		Senior	
		M	SD	M	SD	M	SD	M	SD
SK1	Synthesize, analyse, manage, and report environmental data (pollution emission measurements, atmospheric monitoring, meteorological / mineralogical information processing, etc.)	3.8	1	4.2	0.8	1.5	1.4	3.6	0.9
SK2	Conduct exposure assessments and monitoring; emissions modelling for air, waste or water	3.7	0.8	3.9	1.0	1.7	1.1	3.0	1
SK3	Perform studies to estimate and reduce emissions	4.2	0.7	4.4	0.7	2	1.3	3.5	1.2
SK4	Perform studies to estimate and handle radiation risk	4.3	0.8	4.2	0.8	1.7	1.1	2.4	1.4
SK5	Assess risks of bio-hazardous materials improper manipulation	4.2	0.7	4.3	0.8	1.8	1.2	2.8	1.3
SK6	Remediate contaminated sites	3.7	0.9	4.2	0.9	1.5	1.3	2.8	1.4
SK7	Asses control technologies and conduct safety inspections and audits	3.5	0.8	3.7	1.3	1.2	1.1	2.9	1.4
SK8	Develop environmental and safety procedures and guidelines	3.5	0.8	3.8	1.2	1.5	1.3	3.0	1.3
SK9	Determine data collection methods to be employed in research projects or surveys	3.6	1	3.5	1.2	2	1.2	3.1	1.3
SK10	Prepare charts or graphs from data samples, providing information on the environmental relevance of the data	2.8	1.2	3.4	1.1	1.9	1.1	3.5	1.4
SK11	Measure, audit and evaluate the effectiveness of hazard control programs	3.5	1.1	3.7	1.1	1.6	1.4	3	1.3
SK12	Establish and maintain all required records applicable to safety and environmental compliance of the site	3.7	1	3.7	1.2	1.7	1.1	3.1	1.3
SK13	Collect, analyse and track performance KPIs for continuous improvement and Corporate reporting	3.5	1	3.5	1	1.5	1.1	2.6	1.2
SK14	Drive fulfilment of institutions' Environmental,	3.7	0.9	3.0	1.2	1.1	1.1	2.1	1.4

	Health and Safety policy to foster and maintain a strong and effective EHS culture								
Green abilities (GA)									
GA1	Fundamentals of chemical composition, structure, and properties of substances application.	4.1	0.9	4.2	0.8	2.6	1.1	4.2	0.8
GA2	Use of basic rules of arithmetic, algebra, geometry, calculus and statistics.	3.5	1.1	4.2	0.9	3	1	3.7	0.9
GA3	Application of engineering science and technology practical principles, and living organisms' structure and functions.	3.8	1.1	4.1	0.8	2.7	1	3.3	1
GA4	Specification of sources of pollution, determination of their harmful effects on the environment; performance of hazardous waste treatment operations; administer and advise on hazard control programs.	4.1	1	4.1	0.9	2.8	0.8	3.6	0.9
GA5	Maintenance of an in-depth knowledge and implementation of environmental, safety and industrial hygiene regulatory requirements and best practices.	3.6	1	3.7	0.9	1.6	0.8	3	1.2
GA6	Evaluation and management of environmental, social and health impacts.	3.7	1.0	3.6	0.9	1.9	1.2	2.8	1.3
GA7	Carrying on safety inspections and audits and enforcement of environmental, health and safety standards including ISO 14001.	3.4	0.5	3.9	0.9	1.3	1	3.1	1.4
GA8	Performance of emergency / crisis management in terms of planning and response.	4	0.8	4.2	0.7	2.3	1.1	3.3	1.2

Importance of skills and green abilities was estimated very high at both groups of students. Seniors estimated importance significantly higher ($p<0.05$) at survey item of SK1, SK6, and SK10, while freshmen stressed importance significantly different at SK14. Effect size is moderate (eta squared=0.5-0.8). Importance of green abilities is demonstrated as highly desirable by both groups (Figure 1), while seniors stressed more influence at GA2 and GA7 ($p<0.05$, eta squared=0.11). Considering the gender, there is a significant difference ($p<0.05$) of perceived importance at GA2 and GA3 where male students expressed that using math tools in green chemistry (GA2) and practical implications of science and technology (GA3) have an important role at design and engineering of new products. Effect size is regarded as moderate (eta squared=0.06).

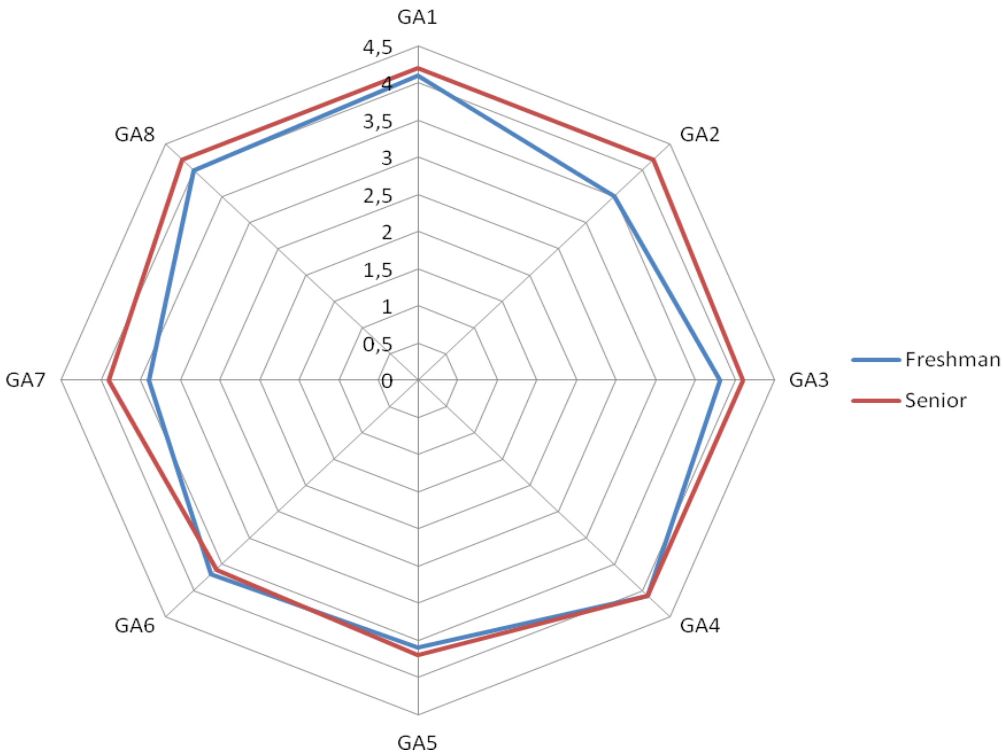

Figure 1. Perceived importance of STRENGTH EHS green abilities in chemical engineering students

Current level of skills and green abilities is relatively poor at freshmen, while at seniors group of students is judged to be moderate (Figure 2). Senior students posed significantly different level of green skills ($p<0.05$) at all items with large effect size (eta squared>0.14). Self-assessed green abilities development at senior students was judged to be significantly moderate to high at all survey items (GA1-8).

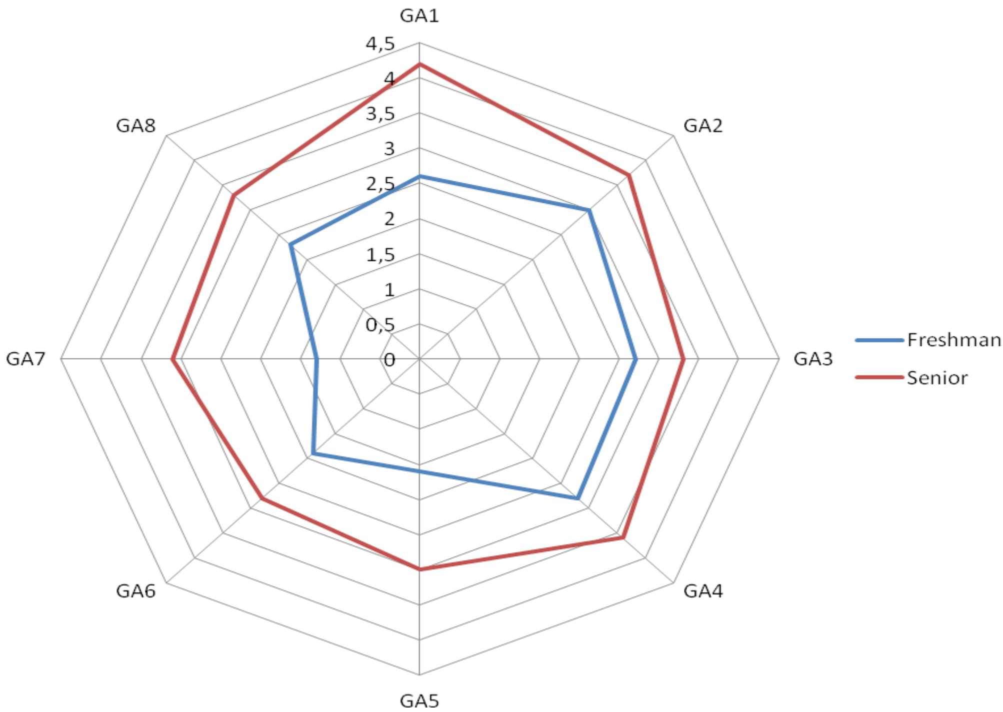

Figure 2. Self-assessed level of STRENGTH EHS green abilities in chemical engineering students

Green abilities acquisition or mastering is distributed almost evenly across the gender; with one exception at GA1 where male students reported higher scores at fundamentals of chemical composition, structure, and properties of substances application achievement. A difference is significant ($p<0.05$) with moderate effect size (eta squared=0.53). Used teaching methods suit both males and females.

Conclusions

The research findings from the present study reveal the importance EHS course design and outcomes.

It is proved that EHS competencies structure is well designed and important for chemical engineering students. Students' perceived importance of green competencies revealed a high level of self-regulation, and motivation towards green jobs' potential, while knowledge of hazardous waste treatment, safety and risk management were decisive for senior students. Green chemistry is satisfactorily implemented during chemical engineering study. For advances; structural changes in curriculum are needed. Senior students significantly higher estimated current level of green abilities mastering. Some abilities need to be enhanced more, such as "Maintenance of an in-depth knowledge and implementation of environmental, safety and industrial hygiene regulatory requirements and best practices" and meta-cognitive skills for "Evaluation and management of environmental, social and health impacts".

A significant lack of self-assessed knowledge is detected at to "Maintain EHS Management Systems, including ISO 14001 registration" and at competence to "Administer Process Safety Management (PSM) and Risk Management Planning (RMP) programs, including Process Hazard Analysis, Pre-startup Safety Review and Management of Change". In general, environmental management knowledge and skills is lacking in existing curriculum and STRENGTH courses show potential to introduce new and important contents into education and training for competitive green jobs.

Many opportunities exist for chemical engineers to support the goals of green engineering. Profession of chemical engineer has made great strides in this effort, but there is still much more to be done. Expediency is essential as is the need for greater corporate and education participation, making it our social responsibility to encourage industrial organizations, educational and research institutions, training and human resource centres, and policy makers to get involved. Perhaps the greatest challenge facing green chemical engineering is the eventual elimination of all environmentally harmful chemical products. In other words, when designing compounds for a particular application, how can we ensure from their conception that they have low toxicity and rapid biodegradability while retaining their desired effect? Chemists are still a long way from being able to predict the properties (both chemical and biological) of compounds on the back of an envelope. Reaching that point is a daunting task, but it will inspire the next generation of chemists.

Further research is required to replicate these findings amongst the other samples, and to identify whether there are specific variations in green practices, and styles that are particularly salient to the development of the research skills, problem-solving ability, and critical thinking and decision-making green abilities.

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