Available online at www.sciencedirect.com
ScienceDirect
Journal of Hazardous Materials 150 (2008) 826–830
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

Short communication

Inherent safety, ethics and human error

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Received 13 August 2007; accepted 16 September 2007
Available online 7 October 2007

Abstract

A patient is to have the damaged left kidney removed. To safeguard correctness of action several layers of expert checks have been performed prior to the operation, which results in the removal of the fully functional right kidney. Nobody asked the patient. The patient did not volunteer providing "unnecessary" information. The experts know everything . . .

An untidy house made out of flammable materials. A careless smoker left his lit cigarette unattended. A blow of wind and the house comes in flames. Would better construction materials have prevented the accident in spite of the carelessness of the inhabitant?

A tricky medical condition which is expected to provoke a patient's fast health deterioration and their slow death. The doctor takes the initiative and responsibility of performing a risky operation. The patient's life is saved and their health is re-established.

This work is not, as initially intended, the result of a thorough investigation of accidents, neither contains a systematic collection of data that can support the conclusions or the suggestions made. It is in the main a compilation of personal views. These views have been established from the correlation of the results of numerous accident investigation reports with the causes of small and insignificant incidents. These incidents are related with the education of university students, regulations within an academic environment and from independent personal experience working in different countries and with people of different cultures. The analysis that follows, however, should not be perceived as a mere reference to university students and/or to a university environment. University is the place where the fundamental scientific and engineering principles are germinated while current and past university students are the future and current production and design engineers, respectively. The places where the presented incidents have occurred are not always relevant with the conclusions, thus they are not stated. The reason this article is presented here is that I believe that often, complex accidents, similarly to insignificant ones, often demonstrate an attitude which can be characterized as "inherently unsafe". I take the view that the enormous human potential and the human ability to minimize accidents needs to become a focal point towards inherent safety. Restricting ourselves to human limitations and how we could "treat" or prevent humans from not making accidents needs to be re-addressed.

The purpose of this presentation is to highlight observations and provoke a discussion on how we could possibly improve the understanding of safety related issues. I do not intent to reject or criticize existing methodologies. (The entire presentation is strongly influenced by Trevor Kletz's work although our views are often different.)

Keywords: Safety and university education; Safety warnings; Inherent safety

1. Safety and education

Numerous accidents can be attributed to the lack of essential technical or scientific knowledge. Essential data and information are either entirely unavailable or, they are not known to the person responsible. More specifically the safety of the chemical industry crucially depends on the good knowledge *of reactivity of chemicals*, *their physical properties*, *incompatibilities*, *etc.*, in other words on the possession of an appropriate scientific background.

If we look at the properties or incompatibilities of substances which have caused an accident for instance, one wonders how the possibility of existence of such incompatibilities could have been given thought and consideration prior to the accident. The immediate question is "was an engineer supposed to posses all relevant knowledge?" or, 'what is a good scientific background supposed to be"?

The question of how many things is a chemical engineer supposed to know and how to learn and *digest* them was always in the forefront of university education. Which knowl-

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doi:10.1016/j.jhazmat.2007.09.121

edge is essential so as engineers become able to promote safety?

2. Targets of my teaching and problems encountered in the effort to communicate them

My primary concern as a university teacher was, prior and simultaneously with the transfer of the pure technical knowledge to students, to equip them with the required means of handling it. More specifically, I was primarily trying to make them aware of the limitations of their and, in fact the limitations of our, knowledge and how to handle it. Major effort was put to facilitate the development of critical thinking and to familiarize chemical engineering undergraduates with the following ideas:

1. We do not know everything. But we do not need to know everything. We should target to develop the ability to identify what we do need to know and *how accurately* we need to know it and what would be merely nice to know.
2. There are different ways of obtaining data. The methodologies that we will follow depend on the need for accuracy, the time available and the resources available.
3. When decisions have to be made in a short time – and in a case of emergency this is something of vital importance – we need to be able to do quick, back of the envelop calculations.
4. There are multiple solutions of a single problem, some better some worse than others but anyway solutions, the quality of which is *condition dependent*.
5. Always use units.
6. Quantify, always quantify and judge your result. Is its order of magnitude right? Are there any surprises?

All these issues appear to be common sense to most engineers. Nevertheless, I have tried to instill these ideas to students through many years of teaching core chemical engineering modules. I was teaching these modules, consecutively in all but the first year of their studies. I have tried different methodologies and I had refined my methods. I have also addressed different audiences. However, I never felt that I had succeeded much. And although one can dispute the correctness of my approaches, in depth discussions with colleagues in different countries and places came down to the same disheartening results: the message was not satisfactorily transmitted and things seem to have deteriorated during the last decade. *Is that important however from a safety point of view*? Before addressing this question, I would like to put down my experiences as a teacher and my views in regard with some potential roots of this failure and subsequently associate it with, in my view, important aspects of *inherent* safety.

a. In spite of some short-lasting appearances of some students' grasping the message, they returned to believe that all properties are known, all reactions pathways and kinetic coefficients are known, in other words everything is known, (luckily our Professors should know everything—we have just to ask them nicely and they will tell us). In the main, throughout their high school years, the audience I was addressing was given problems that only required filling in a number in the final box. I considered therefore, that this attitude was deeply seated in students' minds and it is, as I believed, the result of an educational system that supports the existence of a single "absolute" solution (which, by the way, appears easy to mark and evaluate so as to rank the students fairly).
b. Students were always desperate to find a single number (not to talk about units—too much of a hassle) with 20, 30 decimal digits—the more the better. This approach, I considered had its roots in their absolute reliance on computers. "This is what the computer produced." "The computer gave so many digits." (I was surprised to see that people whom I taught for 4 years and co-supervised over a Ph.D. for another 4 years, go to work in plant design and moan about the time they spent in the theory of the design of distillation columns when a computer can do it all for you.) Here, I partially blamed the use of calculators and computers before learning how to handle numbers, before one is able to deal with mental arithmetic and not to exaggerate, before they understand the importance of quantities. But, simultaneously, I could not help noticing that this apparent inadequacy was most likely the result of unwillingness to put some mental effort rather than inability to think further.
c. I found that students are constantly searching for the "expert". For almost any given problem most students would tend to find "the right person" who would give them effortlessly the required answer. (Nowadays, it is quite often the internet in the form of "google.com".) Although this approach is, in numerous cases, the best first step, it becomes worrying when the users of the expert's opinion do not want to admit any liability if the outcome is wrong "not my fault, this is what the expert said", in other words, "I do not have any responsibility." The look for the expert was more common between "strategic learners" that is students who mainly target, and usually achieve, good performance in the exams.

Moreover, personal experience has shown that not only students, but also long term professional chemical engineers, who are not mostly, but not always, directly involved with production, believe that by adding-up the right safety control or some more equipment (an extra pump for the circulation of coolant in case the first pump fails, they will avert the reaction runaway), all safety problems can be resolved. In other words, although general concepts about safety cross their minds, they believe that we have all necessary tools to design safe processes (the "absolute" knowledge) and there are some "experts" who can do that. Moreover, inherent safety, although fascinating as a concept, is far from being understood in depth and width. Engineers and especially new graduates understand safety as a summary of some abstract ideas of appropriate regulations together with the selection and implementations of appropriate "add-ons".

However, could there exist, other subtle factors influencing students stronger than lectures? And if yes, which ones? I took a look at the ways we react following an accident and on how our society handles small safety issues for a wider public. More specifically I question whether small things which affect our everyday life may have an important impact or our way of thinking, but, being trivial, we tend to disregard them.

3. The add-ons: procedures

Depending on its extent and the place that it occurred an accident is usually followed-up by an investigation and the compilation of a list of recommendations to avert further similar accidents form occurring. However, as "...history shows that the detailed circumstances of any major accident do not repeat themselves; each is unique in its train of events ..." (T. Kletz "learning from accidents", Gulf Professional Publishing, 3rd ed., 2001, p. 203) those, often result in the introduction of new or further *regulations* and more frequently than not add more layers on Trevor Kletz's onion (so, inevitably, the next accident will have more depth to get into).

However, those, especially the ones that address a wider public should be very carefully selected and should be given extensive thought. This is not frequently done and more often than not the promotion of safety for the wider public is done via additional regulations which can be impractical or counter-productive or both. As an example, relatively recent regulations in UK impose that the internal doors of every new house should have a system that keeps them constantly closed, so that in the case of a fire, its consequences are minimized. However, I, personally, like to be able to carry freely my coffee (in one hand) and my books (with the other hand) around the house or listen to the noises that my young child makes playing in his room while I am working. If I had to live in a closed door house, I would definitely try to find a clever law-abiding way to by-pass this mechanism. In fact, I have not visited a house yet, where these mechanisms had been left in operation. And I cannot certainly imagine a university where every lecturer's door closes hermetically following every student's or visitor's departure. However, I also wonder how many people know about the fire triangle. Nevertheless, if a regulation makes people's life impractical it is unlikely to be effective.

A second relevant issue is related with the behaviour of a clever and creative person who has to go through a boring set of detailed procedures and protocols, which, to their mind appear to be needless, or too boring or too plane. Will they follow them? In Piper–Alpha it was the "rebels" that survived; the ones that did not follow the procedures. On the other hand a great number of accidents occur because procedures are not followed. How do we address the creative and knowledgeable people's intelligence? Can here protocols be counter-productive?

4. Safety warnings: how legislation is mishandled

When my son was 30 months old I bought him a scooter which was supposed to be, according to the user's guide, for children aged over 24 months old. When the box was opened and the scooter assembled, a hazard sticker firmly attached on the handle, indicated that the toy contained small pieces, thus it was unsuitable for children younger than 36 months because of *choking* hazard.

If you buy a packet of nuts in Europe you will see highlighted the allergy warning that "it contains nuts".

We had ordered once a chemical, which arrived in a rectangular carton box. On the box there was a large label stating: it is essential that this bottle is always kept up-side down. For this reason the top of the box has been marked "bottom" and the bottom "top".

Although I appreciate the importance of humor in our lives, these warnings transfer the wrong message. *They are not trying to communicate anything*. I believe that they even go further they are frequently an affront to people's intelligence. As a result they are totally disregarded. However, this is quite dangerous as one of the key methods to communicate hazard is weakened. I have repeatedly seen procedures and protocols being completely disregarded and treated as formalities and non-sense only because organizations have looked at legislation from a bureaucratic point of view. On the other hand the labeling of chemicals with their hazard and risk numbers and a few simple well defined sketches, transfer the message very quickly and very effectively. Of course one needs to check what hazards and what risks these numbers correspond too, but these numbers are readily available and the process is simple, easy to implement and throughout meaningful.

5. The blame, the fear and the ethics

In one of the Universities that I have been, which had a good safety record, the following event took place. I should parenthetically say that in terms of the attitude that it demonstrates, this was not an isolated event. A postgraduate student stayed overnight in order to finish some analyses of his results which he did not want to interrupt. As he was working he noticed that a main water pipe burst at around 3 a.m. and the building was flooding. He called University-security who took immediate action and the flood was stopped. In the meantime the flood had damaged some 400,000 GBP worth of brand new equipment. The student's primer research was experimental but he was never doing or was in need to do any experimental work out of working hours. Nevertheless, without having been contacted or interviewed about the event, 3 days later he received an unpleasant letter from the safety officer of the department warning him that he should become aware that experimental work without permission was not allowed out of working hours. The student thought that it would have been better for him not to have informed anybody about the flood and let it carry on until 9 a.m. that staff arrived at work. I have frequently come across similar situations. Due to their fear of a potential blame in regard with their procedures, the safety officer passes on the blame to the person who reported the fault. I do not only question how dangerous that an attitude can be but I also question its ethics.

If you buy a packet of cigarettes in Europe you will be given a box with a big white label that warns you that smoking kills. I do not know anybody that stopped smoking because of that. Initially, it was unpleasant to see later on one got used to that. However, is safety perceived as a dissemination of fear?

Since the age of 11, I was traveling regularly by ferryboat. Shipwrecks were not common, but we used to hear about all of them because lots of our people were working in the merchant navy. However, we had never seen the sea as a danger, we were never afraid of it. I experienced the fear for first time, 20 or more years later, when, due to the implementation of European regula-

tions in my country, upon the boat depart safety procedures were announced. There it was highlighted that it is likely for the boat to come into flames, to sink, to explode ... only then I reconsidered the safety announcements on air-flights, which always introduced a worry in my air-trips, although I adore flying. How likely is it to land a plane safely on the usually rough waters of the Atlantic or on water when it flies over land? Is it *ethical* to spoil somebody's trip and peace of mind with these announcements? Could it not be done in a different more pleasant way? (For instance, with a leaflet provided to you on purchase of your ticket.) Are those announcement really *safety* related? Has their efficiency ever been examined? Have these been selected after serious consideration?

6. The absolute knowledge—the expert

I really feel uncomfortable every time that my young son asks me, which is the maximum possible length of time a human being can live? I feel uncomfortable, because lying is not an option and I know that if I do not give an absolute number in years, months and days I will face the comment "a chemical engineer should know these things". The bad thing is that he always remembers to give me a second chance to prove him that I am a knowledgeable chemical engineer.

I was really astonished to listen to the news that in routine and not emergency operations—patients had the functional part of their body (kidney, leg, tooth, etc.) removed instead of the damaged one. I cannot imagine any procedure where a short interview between the surgeon and the patient does not take place prior to the operation. Anyway, I had shorter or longer experiences with the health system of different countries. In one of those however, I felt very uncomfortable when I visited the doctor and had to be dispensed some medication. Following some questions whether I had or not any allergies I was send to the pharmacy where I was dispensed a container with my name, the name of the medicine, the daily dosage and the total duration of medication. In some European countries, my country included, medication comes pre-packed and it is accompanied by a long description of the detailed composition, side effects, usual dosage, incompatibilities, maximum allowed duration of taking the medication, etc., which was always great to read. This reading had put me totally off using any unnecessary medication—e.g. painkillers. In the country I refer to, I could occasionally obtain those from pharmacies and only on request, on other occasions it was impossible. Moreover, in my country I had always with me a book with my medical record, from childhood, detailing all illnesses and medication which I had received. However, in the country I refer too, I had no medical record directly passed on to me. At the same time due to my moving from place to place, my records held by the clinics I was registered with went into a black hole, so I ended-up with no medical record. I had discussed that with doctors that I knew and I was told that in the past patients were in charge of their own records but they kept loosing them. However, is it safe to centralize and maintain a centralized record keeping system, introducing all the additional administration structures, if the resources necessary to support such a system are not in place? Keeping my own records automatically renders me responsible of my own safety. However, if I am forced to rely on somebody else I will never learn how to keep an eye on me and my health.

In this particular system, in two cases the dosage of my young son's medicine was mixed-up by the chemist (my son was prescribed two things at once). This could possibly have had serious consequences for his health as one of the stated doses following the mix-up was three times higher than the apparently maximum dose allowed—while the other was too small. However, following my old habit, I checked the material safety data sheets of the medicines prior to giving them to him and I spotted the inconsistency, which the doctor whom I contacted, also verified. I appreciate the fact that medication was absolutely free (but overall not necessarily cheaper than the pre-packed ready-to-go medication). However, it is certainly less unlikely to put the wrong label on the bottles of an entire industrial batch rather than having that mistake made by the chemist.

Having seen the above approach though, where all decisions are taken with no patient participation, I can clearly see how it is not only possible but also likely to have a functional part of your body removed when an operation takes place. However, the patient can be made aware of looking after themselves and helping doctors in their duties. To my current knowledge, in countries, where this collaboration occurred, the medical system had not faced any malfunctions because of the aforementioned approach. This example has only been used to highlight how a particular approach on a specific aspect can drive safer practices and not to put any blame on a system that is not functioning as initially intended.

7. The idiots guides

I heard of the conclusions of a research done on children which were as plain as this. Children who were told that they were clever became clever and children who were told they are idiots developed slow. I am sure there are lots of simplifications here; however, during my carrier in the university, in numerous cases the only thing I needed to do in order to convince students to perform a difficult task was to assure them they could do it. However, our culture promotes easy solutions, idiots guide and minimization of brain effort. Often I wonder, how do people feel about their intelligence? Do we try to exercise our brain? Do we try to become cleverer? Or do we prefer our role as an idiot and chose the idiot-proof solutions. This is again related to a topic mentioned earlier of how an intelligent and busy person is going to deal with idiot-proof written procedures. Are they likely to read them carefully, or are they going to skip apparently obvious steps with the possibility of missing something really important?

Looking at the changes that occurred in primary, secondary and tertiary education during the last two decades in Europe, potentially in other places too, one can notice a dramatic reduction of science taught and problem solving and the introduction of more "practical" or "enjoyable" subjects. I suppose this has been driven by the fast technological development, especially in regard with computers, automation and their application and the inevitable changes that accompanied the employment market. However, this has resulted in a partial replacement

of "education" by "training". I will use as an example the computer programming itself. When only students had access to computers "programming" was the key subject taught. An essential part of it was the *development of the algorithm* prior to writing the code. That imposed the need to think of the "whole" problem, all the possible routes that the solution could take, and the ways to handle it. That was a unique exercise in terms of the development of analytical thinking but also the capacity of synthesis and most of all at looking at the problem as a whole. At that time, the students were doing the "thinking" and the computer the "work". This is why computers were invented for. My undergraduate students are not doing any thinking anymore. The computer does the thinking and they do the work.

But do we really need to simplify or reduce the science taught? Was the technological development of the past few decades the result of new science being discovered? Due to the advances in chip-technology we were only enabled to practically apply science which has been more or less known. Reducing science from our courses distances us further and further from the technological achievements of our civilization. In the end of the day it is safer and easier to explain in simple scientific terms how a microwave functions rather than having to warn people that they are not appropriate for drying small animals.

8. Are those important from a safety point of view?

In the process of the investigation of almost every serious accident there is either an explicit or an implicit comment "nobody noticed at the time . . ." However, why?

Because the humans involved in the process have been explicitly or implicitly told that they have well specified tasks and they do not go beyond their well assigned tasks. Lots of reasons could have caused this kind of behaviour. However, often nobody has understood in depth that some dangers do exist. Moreover, everybody trusts the way the system works.

When one establishes procedures and protocols, when a system is built, assumptions are made, order is considered to prevail perturbations of the system are disregarded. However, systems are neither perfect nor self-adjusted mechanisms.

9. Closing remarks

A selection of elements which directly or indirectly affect our perceptions, attitudes and practices in regard with safety was presented in this work. Although certain examples were taken from the university – due to my direct working experience in the respective environment – these do not apply only there, but they are encountered in all different environments. I believe that some wrong perceptions in regard with safety are developed and established by our everyday contact with misleading practices. These perceptions become deeply seated in people's minds so that education fails to eradicate them, probably because these wrong perceptions are also deeply seated in teachers' and trainers' minds, too. Consequently, a great number of professional engineers continue to maintain these attitudes, thus promoting wrong safety practices in plant and process design and operation.

When we come across an accident, our common practice is to impose restrictive measures so as to avert the appearance of similar accidents. In the process of the development of those measures however, people are usually treated as the weak point in the case of events that results in an accident. However, in my view, and this is the focal point of this presentation, people are also the most promising, active and dynamic "element" that could avert the accident from occurring. It is people after all that have made all instruments and controls and developed the methodologies that minimize accidents. And I feel that this "element" is not used to its full or to a decent proportion of its potential.

There is not an easy way, or I do not have one, to achieve that. However, I believe that people interested in process safety should sooner or later consider how we can instigate people to be proactive, rather than responsive. Possibly the first step would be to take a critical view in all levels of education, legislation and communication of safety. The role of science and engineering should be strengthened rather than weakened. Inherent safety concepts should be introduced at earlier stages of education so that its meaning becomes wider in the view of the public.