A knowledge-information-data concept model for engineering education *

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SUMMARY: *Engineering is a knowledge-based industry. In order to produce job-ready engineering graduates, educators need to fully understand and differentiate fundamental terms of the information age such as "data", "information" and "knowledge". These are all familiar terms, but may have different meanings to different people. A simple model is provided in this paper as a common starting point to conceptualise, discuss and ultimately enhance the incorporation of knowledge-information-data (KID) within the engineering curricula. The application of the KID model in translating student feedback and to illustrate course content deficiencies is also described.*

1 INTRODUCTION

This paper outlines a concept model that describes the inter-relationships between data, information and knowledge pertaining to engineering practice. The knowledge-information-data (or KID) concept model is intended to provide a basic framework describing some of the fundamental engineering skills. It is hoped that this framework would provide insights in how improvements can be made to the teaching of undergraduate students, given that engineering is predominately a knowledge-based industry.

A concept model is a simple tool to visualise the main elements and processes that drive a more complicated system. In the context of this paper, the purpose of the concept model is to provide a common ground in relation to key terms, terminology and a basic understanding of underlying principles. A conceptual "mind map" of the definition and linkages between data, information and knowledge is expected to be a useful tool to facilitate communication between stakeholders wanting to enhance engineering education outcomes.

The KID concept model proposed in this paper is assembled from established knowledge theory coupled with the authors' own experience working in industry, and observations of the role and attributes of graduate engineers.

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2 BASIC DEFINITIONS OF DATA, INFORMATION AND KNOWLEDGE

Data, information and knowledge are familiar terms in our daily lives. They can be defined in a multitude of ways to the point that they have become interchangeable in use (Bell, 1999). Selected definitions are provided in table 1, and these have been constructive in development of the KID model.

A hierarchical structure is often used to describe functional relationships between these three key terms, with data as a base or starting point, transforming into information and subsequently leading to knowledge. Various representations of this hierarchy have been made including a continuum or chain (Bell, 1999; Davenport & Prusak, 1998; Lievesley, 2006). A more common representation in the literature is the Data-Information-Knowledge-Wisdom (DIKW) pyramid (figure 1).

DIKW is part of the canon of information science and management, and the subject of much critique and debate (Fricke, 2008; Rowley, 2007). Ackoff (1989) is credited as the first to formally elucidate the DIKW structure, but much earlier conceptions are founded on education theory (a history is documented by Wallace, 2007). Due to its philosophical nature, wisdom is often excluded in the technical-based information sciences, leaving a truncated hierarchy extending from data to knowledge.

Regardless of the underling representation (as a chain or pyramid), it is clear that there is no universal or unifying conceptual framework that defines data, information and knowledge. For example, Lee et al (2006) described several taxonomies of knowledge

Table 1: Various definitions of data, information and knowledge.

Data
"Facts, esp. numerical facts, collected together for reference or information" OED (2004)
"are symbols that represent properties of objects, events and their environment. They are products of observation, but are of no use until they are in a useable (i.e. relevant) form" Ackoff (1989)
Information
"giving form or shape to the mind, as in education, instruction, or training" OED (2004)
"is contained in descriptions, answers to questions that begin with such words as who, what, when and how many… Information is inferred from data" Ackoff (1989)
Knowledge
"is information combined with experience, context, interpretation, and reflection. It is a high-value form of information that is ready to apply to decisions and actions." Davenport & Prusak (1998)
"is the human expertise stored in a person's mind, gained through experience, and interaction with the person's environment." Sunasee & Sewry (2002)
"is know-how, and is what makes possible the transformation of information into instructions. Knowledge can be obtained either by transmission from another who has it, by instruction, or by extracting it from experience" Ackoff (1989)

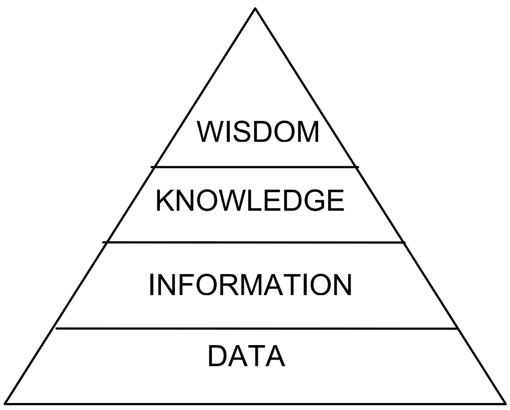

Figure 1: Pyramid representation of DIKW hierarchy.

that differ according to technical discipline. By a series of questionnaires, Zins (2007) documented 130 definitions of data, knowledge and information based on responses from 45 scholars from 16 countries working in the same field of information science. It is as if "the academic community speaks in different languages". With this is mind, the main objective of this paper is to develop a KID concept model specific to engineering education that provides a mechanism for clear, unambiguous communication of the fundamental principles of data, information and knowledge.

3 DEVELOPMENT OF THE KID CONCEPT MODEL

A major function of a concept model is to provide a shared language in order to gain further insights. Concept models are not intended to be definitive or incorporate all interactions, processes or complexities, and are thus inherently interpretive and simplistic.

The main intent of the KID concept model is to provide a broad, opinion-based view and a common definition of terms that engender more efficient communication and analysis of the problems faced by universities in producing effective engineering graduates. As knowledge, information and data are terms that have different meanings to different people, having these key terms specifically defined within a simple framework is thus important. Defining these critical elements introduces the key concepts imbedded within the KID model.

Figure 2 shows the three critical elements in a partly hierarchical structure, indicating "data" symbolically as an underlying base supporting "information" with "knowledge" incorporated as a special form of information. With this structure in mind and consolidating the various interpretations given in table 1, the following definitions apply at a basic, somewhat pragmatic level (although it also acknowledged that the distinctions between data and information is not always clear cut):

- *Data* – are fundamental inputs to engineering practice, such as measurements, surveys and observations, that need to be processed in some way to yield information.
- *Information* – is taken at its most literal sense as anything that "informs" and as such assists engineers in performing their role. This is an extremely broad definition and information can thus take many forms. Examples of information include the general conclusions of a research study, the results of a testing program, predictions from a

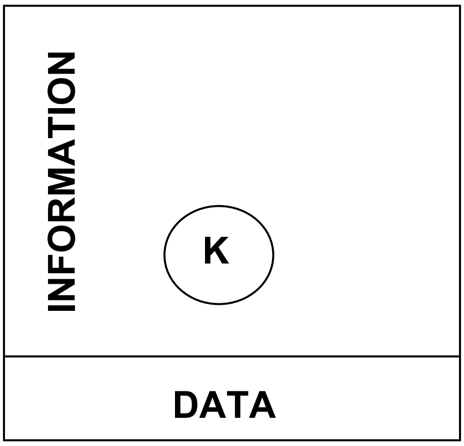

Figure 2: Conceptual structure of data, information and knowledge (denoted as K), with the latter being a special form of information personally held by the individual engineer.

computer model, news of recent developments in engineering and discussions with other engineers who have experienced a similar technical problem. In light of its generic and ever-changing nature, it is considered appropriate to consider information as a "pool" or "store", made up of discrete bits. Another key aspect is that "information" can be (and is mostly) drawn from sources other than those provided to students during their tertiary education.

- *Knowledge* – is a special form of "information". In the KID model, knowledge is simply very useful information that is frequently applied in the day-to-day role of an engineer. It is the high frequency of use and its direct accessibility (recalled from an individual's memory) that distinguishes "knowledge" from the greater pool of available "information". As defined, knowledge has a personal ownership, ie. specific to the individual, and represents a small subset extracted from the information pool. This marks a distinction of the KID model from previous interpretations, such as the DIKW conceptualisation of knowledge as a hierarchal endpoint.

4 INFORMATION IS A COMMODITY

Based on the above definitions, it is appropriate to conceptualise "data" as a raw material requiring processing in some way to provide "information". This is a valid concept as data (for example, a set of measurements or responses from survey questionnaire) would need to be interpreted, statistically analysed or modelled to produce something that will inform or guide engineers.

This analogy of an industrial process that transforms raw material ("data") into something useful ("information") can be taken a step further. In the KID concept model, information is regarded as a commodity as they share a common set of properties. Some commodity-like attributes of information are listed below:

- Information has a shelf life. This can mean that once it is initially obtained, such as taught in an engineering course, a considerable period of time may elapse before a need arises for its use. There is a risk that this relevant piece of information may literally be forgotten.
- Information becomes obsolete and is replaced by newer pieces of information. Thus the store of information that is available is extremely dynamic.
- The store of information is increasing in size and complexity and finding the "right" piece of information is becoming more difficult.
- Information needs to be accessed in a timely fashion in order to be used in the engineering task at hand. How often have you heard the statement "I wish I had that piece of information at the start of the project"?
- Information, in many cases, is disposable in the sense that once it is used it may not be needed again. If information proves to be useful and able to be applied or "recycled" often by the user in future projects, then this information has a higher "knowledge" status.

Recognising that information is a basic commodity of engineering practice is a key concept of the KID model.

5 SKILLS WITHIN THE KID CONCEPT MODEL

Data and information (the latter includes "knowledge" as a readily accessible and often used form of information) are the "building blocks" available to engineers. Using the analogy of data as a raw material and information as a useable commodity, engineers value-add these resources as part of their work. This value-adding involves a range of skill sets and, consistent with the simple basis of the KID concept model, comprise of "data skills", "information skills" and "knowledge skills". These skills are shown diagrammatically as pathways on figure 3, operating at the interfaces between data, information and knowledge.

Data skills are the skills required to yield pieces of information from a set of data. These skills tend to be technical in nature that follow set procedures or use predictive models, rules and equations. They are transformative in that they convert data, which has no or limited meaning, to something that "informs" engineers. A simple example is the calculation of a statistical mean from a set of measured values. This mean can then provide an interpretive piece of information, such as the mean is high/low or unacceptable/acceptable. As defined, data skills play a supportive role in engineering practice.

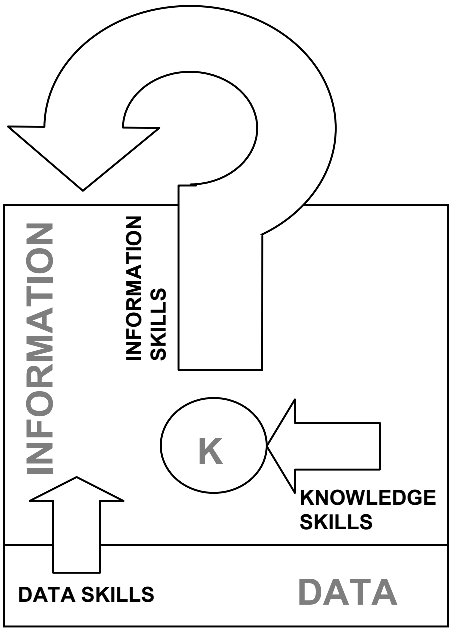

Figure 3: KID concept model showing skill pathways that use data, knowledge and information.

Information skills are essential in engineering practice and are, in the main, the defining attributes of a skilled engineer. In many ways, engineering is the creation, manipulation and utilisation of information. These skills are wide and varying, including creating information (new ideas, innovation), making sound conclusions from the available information (decision-making, structuring recommendations), accessing and finding information (research), and an ability to share and describe information (communication). Information skills are shown on figure 3 as a pathway that taps into the vast "store" of information that includes knowledge, information purposely derived from data and the general "pool" of available information.

Information skills typical employ high-end thinking such as problem solving, ingenuity, planning and management. This distinguishes these skills from data skills that generally follow pre-set procedures. As a guide, various information skills commonly applied in engineering practice are proposed and are listed in table 2. These skills are defined with reference to the KID concept model.

Information skills have a consistency with Bloom's Taxonomy of educational objectives (Bloom, 1956), in which forms of learning are classed, in the cognitive domain, as a sequence of levels starting with "knowing the facts" at the base and working sequentially from comprehension towards evaluation. Learning levels such as comprehension, application, analysis, synthesis and evaluation are useful in influencing educational behaviours, but are considered also to be highly desirable attributes of professional engineers. Accordingly, they can be considered to be "information skills" within the context of the KID model.

The placing of information skills as being of high importance within the KID model is based on the belief of the authors that it is important to distinguish between knowledge (defined as what graduates should "know" to enable them to undertake the roles and responsibilities of early-career professionals) and information (a constantly-changing, dynamic commodity that needs to be accessed by all engineers in order to effectively undertake engineering projects). Thus, engineering students should be equipped with a certain amount of knowledge, but more importantly, should also possess a predefined set of skills and abilities in accessing and working with information.

This view is held by others, such as Laurillard (2002) who, in proposing that new approaches are critically needed in university teaching, stated: "A

Table 2: Proposed "information skills" using the KID concept model as a guide.

Type of skill	As defined within the KID concept model
Analytical planning	Ability to identify what are the "right" pieces of information that are needed
Research	Ability to find the "right" pieces of information from the vast pool of available information
Perception	Ability to fully understand and comprehend pieces of information
Ingenuity and innovation	Ability to create new pieces of information, if required
Problem solving and logic	Ability to organise and interpret pieces of information to address the engineering project objectives
Critiquing	Ability to interrogate information and find flaws
Project management	Ability to deliver information and resources in a timely fashion to achieve the outcomes of the engineering project
Communication	Ability to describe pieces of information in a way that is easily understood

degree certifies the knowledge that graduates have developed when they leave a university, but most graduates use very little of this knowledge in their subsequent careers. The more enduring qualities gained are the skills, attitudes and ways of thinking derived from courses. But degrees and syllabuses are still defined in terms of subject knowledge, rather than generic skills."

Knowledge skills are associated with the maintenance of information personally held and frequently used by the individual. As previously defined, "knowledge" is selected information that is stored in a person's mind and able to be readily accessed. In other words, knowledge is simply "known" information. It reflects the expertise of an individual in their field of engineering. Technical knowledge can be put into three categories: (1) descriptive knowledge – representing statements of fact; (2) prescriptive knowledge – resulting from successive efforts to achieve greater efficiency and added to as experience is gained (eg. rules of thumb); and (3) tacit knowledge – is implicit and results mainly from the outcome of individual judgement, skill and practice (Herschbach, 1995; Vincenti, 1984).

The ability to rapidly draw from this personally-held store of information would obviously enhance the efficiency of an engineer to perform their work. If critical information is missing, then the information skills outlined above would need to be deployed to identify, find and gain a perceptive understanding of the missing information. On this basis, "knowledgeable" engineers would tend to be effective and efficient in the workplace. This means maintaining an up-to-date and comprehensive set of "knowledge" information is considered to be a competitive advantage within the engineering industry.

An important aspect of knowledge is that it supports the work of the engineer. The type of work that an engineer performs changes depending on many factors, including their current position, role within the organisation or stage of their career. To maintain a relevant knowledge base, it is necessary to discard information and refresh new information from time to time. As information is a commodity, so is knowledge, albeit one that is closely held. Thus the main "knowledge skill" of an engineer is to recognise when there is a knowledge deficiency and new information is needed to achieve their personal career goals. For some engineers this may equate to a "topping-up" by keeping current with recent technical developments within their industry. For others, it may be a full renewal of knowledge if there is a major change in career or role, such as a move from a technical position to a managerial position.

The half-life of engineering knowledge ranges from two to seven years, with five years being a reasonable working estimate (Jamieson, 2007). This is an important statistic. It implies that the transmission of knowledge by engineering educators should focus on the early-career phase of engineering students, as post-graduation there is a frequent need for knowledge renewal.

6 USING THE KID CONCEPT MODEL TO "TRANSLATE" ENGINEERING EDUCATION ISSUES

Anecdotal feedback from students and employers can be brought back to a common point of reference, in this case the KID concept model. This provides a mechanism to direct improvements and change within an engineering curriculum. Table 3 provides a set of hypothetical, but typical, anecdotes and how these can be translated using KID terminology.

7 USING THE KID CONCEPT MODEL TO ILLUSTRATE COURSE CONTENT DEFICIENCIES

In addition to "interpreting" feedback from students and employers, the KID concept model can be used to illustrate deficiencies that may be present within a particular engineering curriculum. It provides a

Table 3: Translation of anecdotal statements using KID concept model terms.

Anecdote	Translation based on KID model
"I don't know why I was taught this material as I haven't used it since I graduated"	The course provided me with a static store of information that is now irrelevant or obsolete. It was assumed that all information content in the course is "knowledge", but this is not the case.
"Graduates these days do not know how to be engineers … we have to teach them on the job"	Graduates lack the "information skills" necessary for them to function as engineers
"I have calculated the number, but I don't know what it means"	My "data skill" is good, but my "information skill" is lacking … especially perception
"Life-long learning is important during an engineering career"	It is important to regularly review and update your "knowledge" during your career

tool to communicate important issues; an important step in promoting discussion and hence setting improvements in train. Again, having a concept model with concise and predefined terms is crucial in making sure that these deficiencies (and their solutions) are well communicated.

Figure 4 is an example schematic based on the KID concept model that illustrates the deficiencies of a hypothetical engineering curriculum. It is a generic example, but describes commonly perceived faults in some approaches to engineering education.

In reference to figure 4:

(1) Data skills are overemphasised. Too much of the course content is dedicated to predictive analysis, computer models, algorithms and statistics that mechanically convert data into pieces of information. The interpretation and meaning of the generated information (important information skills) are generally overlooked.

(2) The course curriculum is only providing a static store of information, much of which will become irrelevant and obsolete. All presented information is regarded as "knowledge". Information should be viewed as a dynamic commodity that can be created, accessed, used and often discarded, so information skills (rather than the information itself) are critical.

(3) Knowledge, which is the set of information pieces that a graduate will most likely utilise on a frequent basis in their early career, is not clearly delineated from the clutter of information that is taught. The need to regularly review and update knowledge (a key knowledge skill) on an ongoing basis is not actively encouraged.

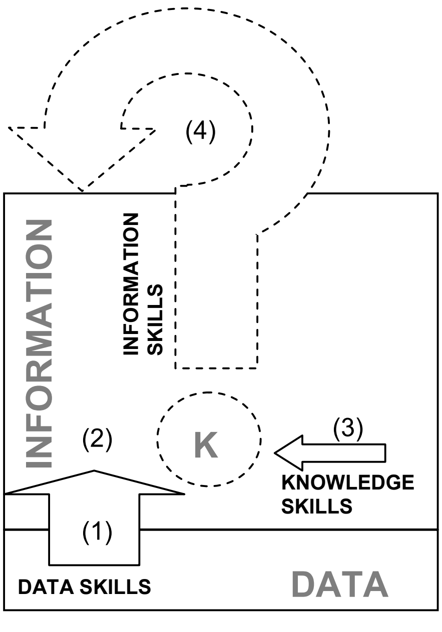

Figure 4: Schematic based on the KID concept model that illustrates the deficiencies of a hypothetical engineering curriculum.

(4) All information skills necessary to practice as an engineer have not been explicitly recognised and taught within the course. Fundamental skills such as project management and communication are incorporated in the curriculum, but not other skills such as analytical planning, research, perception, ingenuity/innovation and problem solving. This is a major failure of the course.

KID principles have particular application in enhancing the content of engineering courses. If there is no clear demarcation between knowledge and information, then all of the educational materials delivered in a course are of equal value. The end result is that for many students, even though having passed the course, there is no guarantee that they have acquired the core elements that they need to "know". This outcome is further reinforced if a quantitative approach to assessment is used to grade students (Biggs, 2002).

Thus, required knowledge to be gained by students on completion should be clearly articulated within the course materials and it is important a deep understanding of this content is promoted. Other parts of the course materials can be informative. Students should have at least a shallow understanding of this information but, more importantly, should appreciate how this information could be used. In this context, the main purpose of providing this information is not to gain "knowledge", but to provide an easy entry point for students to develop and test their "information skills".

The above statement seems commonsense, but the indications are that partitioning knowledge and information is not common practice. Again, quoting Laurillard (2002): "Universities are comfortable teaching specialist knowledge produced by experts, but the practitioner knowledge and the skill to develop it, which is what the knowledge industry needs, is not a natural part of university curricula."

8 CONCLUSIONS

A simple concept model can provide a useful vehicle to communicate aspects of a more complicated system. A concept model is proposed in this paper that defines and links data, information and knowledge in the context of engineering education. The purpose of the KID model is to provide a basic common starting point to discuss ways to enhance the delivery of engineering skills to undergraduate students.

"Data" are the basic building blocks of engineering practice, but a set of computational and interpretative skills ("data skills") are required to yield "information" from the data. "Information" is anything that informs the engineering task at hand, and as broadly defined, can include potentially a vast array of technical information, outcomes of discussions, etc. Thus information can be drawn from a large pool of informal and formal sources, so "information skills" are critical in ensuring that the "right" information is used. In a sense, information is a commodity that is fit for a certain purpose. Information skills also include a range of capabilities when working with information such as problem solving, analytical planning, project management and communication.

"Knowledge" is defined as information that is "known" by the engineer from previous training and work experience and, as it is stored in a person's mind, is readily accessible. Our main role as university educators is to equip engineering graduates with a certain amount of "knowledge" to sustain them through their early-career phase (3 to 5 years post-graduation), as well as the necessary data and information skills that they will encounter in practice. We should also provide them with the skill of regularly updating their knowledge ("knowledge skills" – or lifelong learning) in a way that is compatible with their stage of career or engineering role.

The above interpretations of data, information, knowledge and their respective skills form a starting point for further research, including:

1) testing of the veracity of the KID model across a range of engineering disciplines
2) elucidation of the full set of information skills that are needed, particularly those skills aligned with the graduate attributes set by Engineers Australia
3) identification and evaluation of effective ways to partition knowledge from information presented within engineering course materials
4) determination of the appropriate balance of KID skills to be incorporated within engineering curricula.

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