

Theoretical and practical issues in evaluating the quality of conceptual models: current state and future directions

Daniel L. Moody *

*Department of Computer Science, University of Iceland, Reykjavik, Iceland
Gerstner Laboratory, Czech Technical University, Prague 13000, Czech Republic*

Received 14 December 2004; accepted 14 December 2004

Available online 12 January 2005

Abstract

An international standard has now been established for evaluating the quality of software products. However there is no equivalent standard for evaluating the quality of conceptual models. While a range of quality frameworks have been proposed in the literature, none of these have been widely accepted in practice and none has emerged as a potential standard. As a result, conceptual models continue to be evaluated in practice in an *ad hoc* way, based on common sense, subjective opinions and experience. For conceptual modelling to progress from an “art” to an engineering discipline, quality standards need to be defined, agreed and applied in practice. This paper conducts a review of research in conceptual model quality and identifies the major theoretical and practical issues which need to be addressed. We consider how conceptual model quality frameworks can be structured, how they can be developed, how they can be empirically validated and how to achieve acceptance in practice. We argue that the current proliferation of quality frameworks is counterproductive to the progress of the field, and that researchers and practitioners should work together to establish a common standard (or standards) for conceptual model quality. Finally, we describe some initial efforts towards developing a common standard for data model quality, which may provide a model for future standardisation efforts.

© 2005 Elsevier B.V. All rights reserved.

* Current address: Department of Computer Science, University of Iceland, Reykjavik, Iceland, 107.
E-mail addresses: dm@hi.is, dmoody@labe.felk.cvut.cz

Keywords: Conceptual model; Software quality; Measurement; Requirements analysis; Quality management; Standardisation; Technology transfer; Empirical validation

1. Introduction

1.1. Conceptual modelling

Conceptual modelling is the process of formally documenting a problem domain for the purpose of understanding and communication among stakeholders [118]. Conceptual models are central to IS analysis and design, and are used to define user requirements and as a basis for developing information systems to meet these requirements [131]. More generally, they may be used to support the development, acquisition, adaptation, standardisation and integration of information systems [82]. Conceptual modelling may be used to define user requirements at several different levels:

- Application level: an application-level model defines requirements for a specific information system and provides the basis for developing or acquiring a system to meet those requirements [6].
- Enterprise level: an enterprise model defines information requirements for a whole organisation and provides the basis for enterprise-wide management of data or business processes [117].
- Industry level: a reference model defines information requirements for an entire industry and provides the basis for industry-wide standardisation and development of generic software solutions [2,39].

Conceptual modelling naturally belongs as a subdiscipline of *requirements engineering* (as conceptual models are used to define user requirements) and *software engineering* (as conceptual models are used to develop, acquire or modify information systems). Some might argue that conceptual models are not necessarily used to develop systems and should be evaluated as representations of the “real world” [131]. This paper takes the *critical-realist* view that conceptual modelling is a design discipline and that conceptual models are design artifacts used to actively *construct* the world rather than simply describe it [59,120]. In practice, almost all conceptual models are used directly or indirectly to develop, acquire or modify information systems.

1.2. Why conceptual model quality is important

The traditional focus of software quality has been on evaluating the final product [9,126]. However empirical studies show that more than half the errors which occur during systems development are requirements errors¹ [37,73,85]. Requirements errors are also the most common cause of failure in systems development projects [37,121,122]. The cost of errors increases expo-

¹ A requirements error is defined as where the requirements specification does not match actual user requirements. A design or implementation error is defined as where the design or implementation does not match the requirements specification [73].

nentially over the development lifecycle: it is more than 100 times more costly to correct a defect post-implementation than it is to correct it during requirements analysis [18]. This suggests that it would be more effective to concentrate quality assurance efforts in the requirements analysis stage, in order to catch requirements errors as soon as they occur, or to prevent them from occurring altogether [141].

Improving quality of conceptual models is also likely to improve quality of delivered systems [20,22,131]. While a good conceptual model can be poorly implemented and a poor conceptual model can be improved in later stages, all things being equal, a higher quality conceptual model will lead to a higher quality information system. Thus conceptual model quality may affect both the *efficiency* (time, cost, effort) and *effectiveness* (quality of results) of IS development. For example, a poor quality conceptual model may increase development effort (as a consequence of detecting and correcting defects) or result in a system that does not satisfy users (as a consequence of *not* detecting or *not* correcting defects). In a recent study on the impact of requirements errors, Lauesen and Vinter [73] found that in practice, most requirements errors are *not* corrected. Given fixed schedules and budgets, it is often too expensive and/or politically unacceptable to correct requirements errors discovered after the analysis stage. This means that requirements errors are more likely to affect the quality of the final system than development costs.

1.3. Current state of practice

Currently, the practice of evaluating quality of conceptual models has more of the characteristics of an art than an engineering discipline (see Fig. 1). There are no generally accepted guidelines for evaluating the quality of conceptual models, and little agreement among experts as to what makes a “good” model. While an international standard exists for evaluating software systems [62], no equivalent standard for evaluating quality of conceptual models has so far been proposed. A number of quality frameworks have been proposed in the literature, but none of these have been widely accepted in practice and none has emerged as a potential standard. In the absence of any consensus about how quality should be evaluated, practitioners continue to evaluate conceptual models in an ad hoc and subjective way, based on common sense and experience [71,97]. However for conceptual modelling to progress from an art to an engineering discipline, quality standards need to be defined, agreed and applied in practice.

There are a number of possible explanations for the lack of consensus in this area. Firstly, it is easier to evaluate the quality of a finished product than a logical specification [126]. A conceptual model exists only as a construction of the mind, and therefore quality cannot be as easily assessed. While the finished product (the software system) can be evaluated against the specification, a conceptual model can only be evaluated against people’s (tacit) needs, desires and expectations. Thus the evaluation of conceptual models is by nature a *social* rather than a technical process, which is inherently subjective and difficult to formalise² [79]. Finally, the conceptual modelling field is less mature and there has been less time for a consensus to emerge: research in software quality pre-dates that in conceptual model quality by over a decade (e.g. [19,87]).

² While some errors can be detected automatically (e.g. using automated tools), most errors can only be detected with the involvement of humans [82,98].

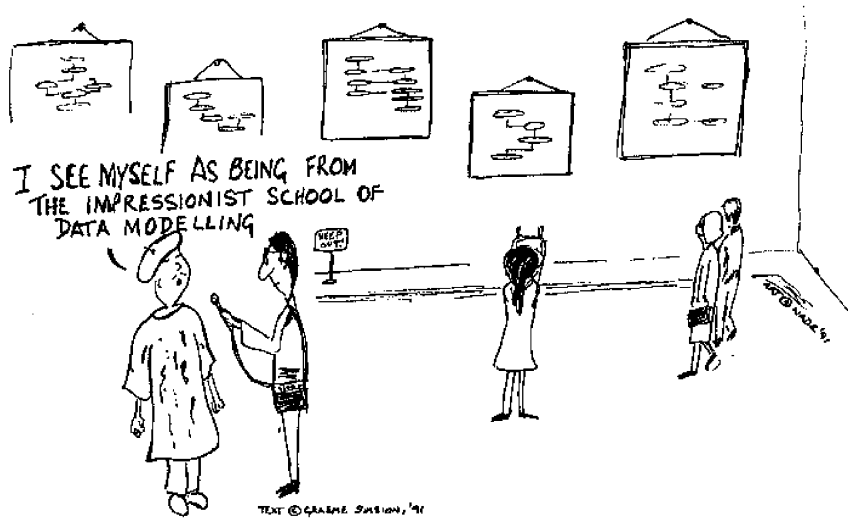


Fig. 1. Conceptual modelling: art or science?

1.4. Objectives of this paper

This paper reviews the current state of research in conceptual model quality and identifies the major theoretical and practical issues that need to be addressed.

- Section 2 reviews existing research in conceptual model quality.
- Section 3 looks at possible ways of structuring conceptual model quality frameworks.
- Section 4 looks at possible ways of developing conceptual model quality frameworks.
- Section 5 looks at ways of empirically validating conceptual model quality frameworks.
- Section 6 looks at how to achieve practitioner acceptance of conceptual model quality frameworks.
- Section 7 concludes with some recommendations for future research.

2. Review of research

2.1. Summary of previous research

A literature search was conducted for previous research in conceptual model quality, covering both academic and practitioner sources. This was done via a keyword search using two of the leading IS literature search engines (Ingenta and Proquest [114]) and by retrieving secondary citations (nested search). The leading researchers in the field were also contacted to verify whether any relevant publications had been omitted. Over 50 separate proposals³ were identified, although

³ The term “proposal” is used instead of “framework” because while some of the entries in the table define complete frameworks for evaluating quality, others focus on a single aspect of quality.

some of these represent extensions or refinements to previous proposals. While it is not possible to be certain that this list is exhaustive, it represents a reasonable starting point for analysis. The scope of the review was limited to research on quality of conceptual modelling products (*scripts*) not conceptual modelling notations (*grammars*) [131].

The proposals identified are summarised in Table 1:

- **Proposal:** this lists the publication(s) describing the proposal. Multiple citations are included when the proposal has been subsequently revised or extended. While most have been “one off” publications, some have been refined and extended several times and have generated substantial bodies of research since they were originally proposed (e.g. [15,79,99]).
- **Level of generality:** whether the proposal focuses on conceptual models generally, a particular class of models (e.g. data models) or models represented using a particular notation (e.g. ER models).
- **Scope:** whether the proposal focuses on quality generally or a particular aspect of quality (e.g. stability).
- **Origin:** whether the proposal emerged from research (R), practice (P) or collaboration between the two (C). This was determined based on affiliations of authors. Most have emerged from research, some from practice and only two as a result of collaboration.
- **Empirical validation:** how the proposal has been empirically validated. This only includes empirical studies used to evaluate the validity of proposals and not to develop them (e.g. [80,81]) or illustrate their use (e.g. [83,135]).

2.2. Research issues

Here we identify the major theoretical and practical issues in the existing research.

2.2.1. Proliferation of proposals

The proliferation of different proposals is now a serious issue. Over 50 different proposals have been published and new ones continue to be published every year. On the positive side, this indicates that a lot of thought has gone into the problem and that among the various proposals a workable solution is likely to be found. On the downside, the number of alternative proposals creates confusion for practitioners in deciding which to use. It is also counterproductive to research progress in terms of establishing a cumulative tradition and a common paradigm [72,133]. The existence of multiple competing proposals is the sign of an immature research field and results in fragmentation of research efforts. Currently, there seems to be little progress towards developing consensus on a common framework.

2.2.2. Lack of empirical testing

Empirical testing is one of the cornerstones of the scientific method [104]. Each proposal can be considered as a “theory” about what conceptual model quality is and how it can be evaluated. The validity of these theories needs to be tested empirically rather than justified by logical or theoretical arguments alone. Only a minority of the proposals (less than 20%) have been empirically validated. The number of new proposals continues to outnumber the empirical studies

Table 1
Proposed approaches to conceptual model quality

Proposal	Level of generality	Scope	Origin	Empirical validation
Martin [86]	IE models	Quality	P	
Barker [10]	ER models	Quality	P	
von Halle [128]	ER models	Quality	P	
Gray et al. [53]	ER models	Complexity	R	
Eick [36]	Conceptual models	Quality	R	
Batini et al. [14]	EER models	Quality	R	
Veryard [127]	ER models	Quality	P	
Zamperoni and Lohr-Richter [140]	Data models	Quality	R	
Marche [83]	Data models	Stability	R	
Lindland et al. [69–71,79,103]	Conceptual models	Quality	R	Laboratory experiments [101,102]
Reingruber and Gregory [109]	Data models	Quality	P	
Moody and Shanks [93,94,97–99]	ER models	Quality	C	Action research, laboratory experiments [92,96,97,100,115]
Simsion [119,120]	ER models	Quality	P	
Levitin and Redman [78]	Data models	Quality	C	
Kesh [68]	Data models	Quality	R	
Becker et al. [15–17,111,113,129,130]	Conceptual models	Quality	R	Action research [110]
Halpin [54,56]	ORM models	Quality	R	
Assenova and Johannesson [4]	Data models	Understandability	R	
Maier [80–82]	Data models	Quality	R	
Teeuw and van den Berg [124]	Process models	Quality	P	
Shanks and Darke [116]	Conceptual models	Quality	R	
Hoxmeier [60]	Data models	Quality	R	
Lehner et al. [76]	Dimensional models	Quality	R	
Misic and Zhao [90]	Reference models	Quality	R	
Yoon et al. [139]	Data models	Quality	R	
Poels and Dedene [107]	OO models	Complexity	R	
Genero et al. [49]	EER models	Complexity	R	Case study [49], laboratory experiments [47,106]
Genero et al. [50]	UML class models	Complexity	R	Laboratory experiments [44,46,48]
Thalheim [125]	ER models	Quality	R	
Armour and Miller [3]	Use case models	Quality	P	
Wedemeijer [134]	Data models	Stability	R	
Cherfi et al. [25]	EER models, UML class models	Quality	R	
Marjomaa [84]	Conceptual models	Quality	R	
Bansiya and Davis [9]	OO models	Quality	R	Case study, laboratory experiment [9]
Lechtenborger and Vossen [74]	Dimensional models	Quality	R	
Levene and Loizou [77]	Dimensional models	Quality	R	
Fettke and Loos [39]	Reference models	Quality	R	
Cherfi and Prat [26]	Dimensional models	Quality	R	
Genero et al. [45]	UML Statechart models	Complexity	R	Laboratory experiment [45]

conducted, which is a sign of immaturity in a research field [72]. For conceptual model quality to progress as a research field, more scientific validation methods are needed [108].

2.2.3. *Lack of adoption in practice*

The ultimate objective of research in conceptual model quality is (or should be) to improve the quality of conceptual models developed in practice. However the research which has been conducted so far seems to have had little impact on conceptual modelling practice. None of the proposals have been widely accepted in practice and many have never have been applied outside a research environment. Regardless of the potential benefits of these proposals, the benefits cannot be realised unless they are *used* in practice. If research in conceptual model quality is to become more than just an academic exercise, researchers need to address the issue of practitioner acceptance. This relates to the more general issue of knowledge transfers from research to practice (*technology transfer*) [66,95].

2.2.4. *Different levels of generality*

The proposals represent a broad range of levels of generality, from ones applicable to all conceptual models to those applicable only to models represented using a particular modelling notation. The more general the proposal, the wider its scope of application, but also the more difficult it is to operationalise in practice. Quality criteria must be defined at a very abstract level and lack details of the types of quality problems (defects) to look for [16]. In general, proposals which have emerged from research tend to be more general while those which have emerged from practice tend to be more specific. This raises questions about what is the most appropriate level of generality and how to resolve the conflict between scope of application and practical applicability.

2.2.5. *Lack of agreement on concepts and terminology*

There is a lack of standardisation of concepts and terminology in the research, reflecting the fragmented nature of the field [82]. Different proposals use different terminology for the same or similar concepts. For example, *quality characteristics* as defined in ISO 9000 [61] are variously called *quality dimensions*, *factors*, *principles*, *views*, *properties*, *attributes*, *criteria*, *categories*, *goals* and *objectives*. Curiously, none of the proposals use the ISO terminology. There is also no agreed definition of conceptual model quality in the literature. Most proposals refer to “conceptual model quality” without defining what it means.

2.2.6. *Lack of consistency with related fields and standards*

As well as a lack of agreement among the proposals themselves (*internal consistency*), there is also a lack of consistency with the related fields of software quality and quality management (*external consistency*). There are remarkably few references to software quality or quality management literature and lack of consistency with relevant international standards in software quality (ISO/IEC 9126) and quality management (ISO 9000). This is surprising, as conceptual model quality logically belongs as a subset of these fields rather than being entirely separate and unrelated. Research in conceptual model quality should build on the foundations of these more mature fields rather than developing new concepts from first principles.

2.2.7. Lack of measurement

Most proposals specify quality criteria without defining how these should be *measured*. As a result, the criteria must be applied in a subjective way. According to the quality management literature, measurable criteria for assessing quality are necessary to avoid “arguments of style” and to improve the reliability of evaluations [38]. A clear research priority should therefore be to develop formal metrics for measuring quality of conceptual models to reduce subjectivity and bias in the evaluation process [108].

2.2.8. Lack of evaluation procedures

According to ISO 9000 [61], quality management procedures should define:

- how inspections should be conducted;
- when they should be conducted;
- who should be involved and their role in the inspection process.

With a few exceptions [82,97,109], most of the proposals do not specify details about how quality evaluations should be conducted. They specify quality criteria (what) without defining the process by which they should be applied (how). This is a barrier to their effective use in practice.

2.2.9. Lack of guidelines for improvement

Quality evaluation is normally only a means to an end: the ultimate aim is to improve the quality of the product to acceptable levels. Most conceptual model quality proposals focus exclusively on quality evaluation (*defect detection*) and ignore the issue of how to improve it (*defect correction*). Thus while they may help in identifying potential quality problems, the analyst must rely on their own resources to solve them.

2.2.10. Focus on static models

The majority of the proposals focus on *static* (data or information) models, which may reflect the higher level of maturity and standardisation of notations in this area. Dynamic models—which define the *functionality* of the system—have so far received very little attention in the literature, even though functionality is widely considered to be the most influential determinant of the quality of the final system [62].

2.2.11. Focus on product quality

The distinction is often made in the quality management literature between product and process quality [61]:

- Product quality focuses on the quality of the end product. Product quality criteria are used to conduct inspections of the finished product and to *detect* and *correct* defects.
- Process quality focuses on the quality of the production process. Process quality focuses on *defect prevention* rather than detection, and aims to reduce reliance on mass inspections as a way of achieving quality [31]. The objective is to build quality into the production process rather than trying to add it in at the end.

According to the quality management literature, the most effective way to improve quality of products is to improve the process by which they are produced [31,38]. Product quality is an inefficient way of achieving quality as it results in waste and rework: errors must be detected and then corrected [38]. Typically, the same errors are repeated over and over again, leading to a continuous cycle of waste and rework. Process quality focuses on identifying and eliminating *root causes* of errors and thus preventing errors from occurring in the first place. So far, conceptual modelling quality research has focused almost exclusively on product quality: very few proposals even mention the issue of process quality [81,82,108].

2.2.12. Lack of knowledge about practices

So far, there have been no empirical studies (with the exception of some case studies reported in [82]) conducted to evaluate current practices in conceptual model quality. That is, what methods do practitioners use (if any) to evaluate quality of conceptual models? While many papers prescribe how quality of conceptual models *should* be evaluated, little is known about what actually happens in practice. Research often lags practice in the IT field, and knowledge about practices can help to inform and guide research efforts [66]. This relates to the issue of knowledge transfers from practice to research, which is the converse of Issue #3.

2.3. Conclusion

This section has identified a number of issues in the existing research in conceptual model quality (summarised in Box 1). In particular, the proliferation of different proposals (#1), lack of empirical testing (#2) and lack of agreement on concepts and terminology (#5) all reflect the immaturity of this research field. The lack of adoption in practice (#3) and lack of knowledge about current practices (#12) reflects a gap between research and practice. Each of the issues identified is addressed (to at least some extent) in subsequent sections of the paper.

Box 1. Conceptual model quality research issues

- #1 Proliferation of proposals.
- #2 Lack of empirical testing.
- #3 Lack of adoption in practice.
- #4 Different levels of generality.
- #5 Lack of agreement on concepts and terminology.
- #6 Lack of consistency with related fields and standards.
- #7 Lack of measurement.
- #8 Lack of evaluation procedures.
- #9 Lack of guidelines for improvement.
- #10 Focus on static models.
- #11 Focus on product quality.
- #12 Lack of knowledge about practices.

3. Structure of quality frameworks

This section examines what conceptual model quality is, how it fits into the wider context of software quality and quality management and possible ways of structuring conceptual model quality frameworks.

3.1. *What is conceptual model quality?*

Discussions of conceptual model quality should begin with a definition of what it *is*. However, currently there is no agreed definition of conceptual model quality in the literature (Issue #5). Any such definition should be consistent with the ISO 9000 definition of quality:

“The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs” [61].

A possible definition of conceptual model quality is therefore:

“The totality of features and characteristics of a conceptual model that bear on its ability to satisfy stated or implied needs”.

While this is a very broad definition, it is consistent with ISO 9000 (Issue #6) and at least provides a starting point for achieving consensus.

3.2. *The wider context of conceptual model quality*

One of the problems with the existing research is the lack of reference to and consistency with the broader fields of software quality and quality management (Issue #6). These fields are much more mature and have well-established international standards:

- ISO 9000 (quality management) defines an overarching framework of quality concepts, terminology, principles and processes which apply to all products and services.
- ISO/IEC 9126 (software product quality) defines a framework for evaluating quality of software products, which covers the entire software development lifecycle and is consistent with ISO 9000.⁴

Conceptual model quality frameworks should be consistent with ISO 9000, as within this framework, a conceptual model is simply a particular type of product. They should also be consistent with ISO/IEC 9126 as conceptual models exist as models of information systems.⁵ Consistency with ISO/IEC 9126 is the most immediate concern, as consistency with this guarantees consistency with ISO 9000 (Fig. 2).

⁴ ISO/IEC Joint Technical Committee 1 is currently working on a second generation of software quality standards called SQuARE [123]. These are not considered here as they are still under development.

⁵ An application-level model is a model of a single information system, while enterprise or reference models are models of multiple information systems.

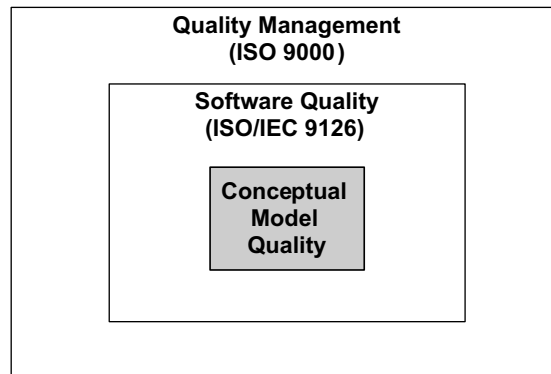


Fig. 2. The broader context of conceptual model quality.

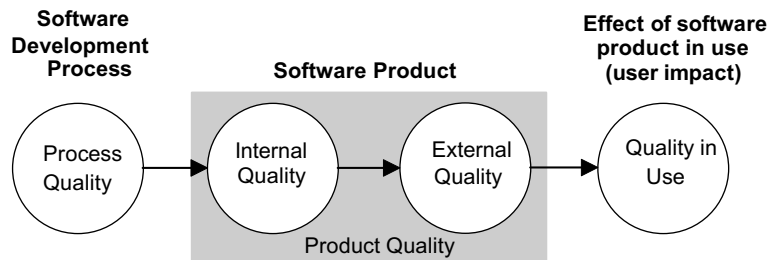


Fig. 3. Quality categories (ISO/IEC 9126).

ISO/IEC 9126 classifies software quality into four categories (Fig. 3):

- Process quality: quality of software lifecycle processes.
- Internal quality: quality of intermediate products, including static and dynamic models, documentation and source code.
- External quality: quality of the final system as assessed by its external behaviour.
- Quality in use: effect of the system in use—the extent to which users can achieve their goals using the system.

Within this framework, conceptual model quality falls into the category of *internal quality*, as conceptual models are intermediate products in the software development process [1]. As shown in Fig. 3, there are also causal linkages between the different categories of quality:

- Process quality → internal quality: improving the quality of software development processes will lead to higher quality software products.
- Internal quality → external quality: improving quality of intermediate products will help to achieve desired system behaviour.
- External quality → quality in use: appropriate system behaviour will enable users to achieve their goals.

This suggests that conceptual model quality (*internal quality*) will help to improve quality of the final system (*external quality*) as argued in Section 1.

3.3. ISO/IEC software quality model

Most approaches to quality evaluation decompose the concept of quality into a set of lower level *quality characteristics* which are recognisable properties of a product or service [9]. This helps to refine abstract notions of “quality” into something more concrete and measurable. ISO/IEC 9126 decomposes the concept of software quality into six *quality characteristics*, which are further divided into 24 *quality subcharacteristics*, which are measured by 113 *quality metrics*. This defines a three level hierarchy of concepts as shown in Fig. 4.

The top level concepts in the hierarchy (software quality characteristics) are summarised in Fig. 5.

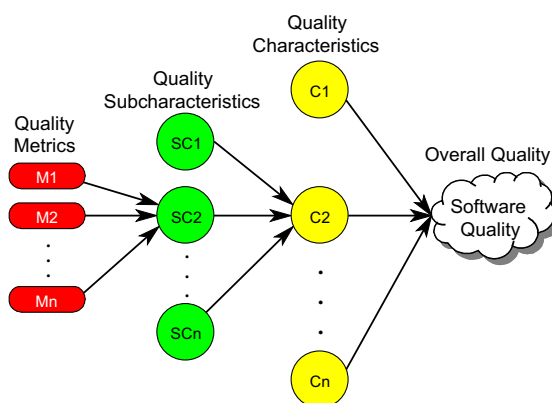


Fig. 4. Structure of ISO/IEC 9126 software quality model.

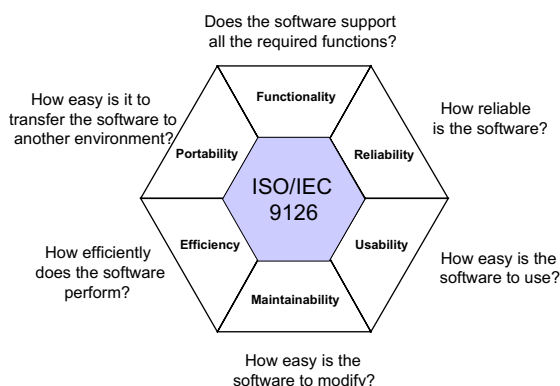


Fig. 5. The six software quality characteristics (ISO/IEC 9126).

ISO/IEC 9126 provides a possible template for structuring conceptual model quality frameworks. The most important features of the ISO/IEC 9126 software quality model are:

- Hierarchical structure: it defines a three-level (strict) hierarchy of quality concepts. Most conceptual model quality frameworks consist of simple lists of quality criteria, which suggests that they need to be refined to another level (or levels) of detail.
- Familiar labels: single words are used to identify each characteristic and subcharacteristic, using terms that are commonly understood in practice (Fig. 5). Many quality criteria proposed in the conceptual model quality literature have names consisting of multiple words and often use unfamiliar or highly theoretical terms. Use of familiar terminology is likely to increase likelihood of acceptance in practice (Issue #3).
- Concise definitions: each characteristic and subcharacteristic is defined using a single sentence (Fig. 5). Many of the conceptual model quality criteria proposed in the literature lack clear and concise definitions.
- Measurement: at the lowest level of the model, metrics, consisting of a measurement method and scale, are defined for all quality subcharacteristics. This means that the evaluation model is *operationally defined* and is not reliant on subjective interpretations of concepts. The lack of measurement is a major weakness in the conceptual model quality literature (Issue #7).
- Evaluation procedures: a separate standard (ISO/IEC 14598: Software Evaluation Process) defines procedures for conducting product evaluations [63]. This specifies *who* should be involved in evaluations and *how* and *when* they should be conducted in the product lifecycle. This is a glaring omission in the conceptual model quality literature (Issue #8).

3.4. Dromey's framework for quality models

Dromey [35] has proposed a framework for structuring software quality models, which provides an alternative to the approach used in ISO/IEC 9126. He argues that approaches based on hierarchical decomposition of quality such as ISO/IEC 9126 are inherently flawed, and that a model consisting of a single level of tangible, quality-carrying properties is simpler and more powerful. Dromey's framework consists of three types of constructs with causal linkages between them (Fig. 6):

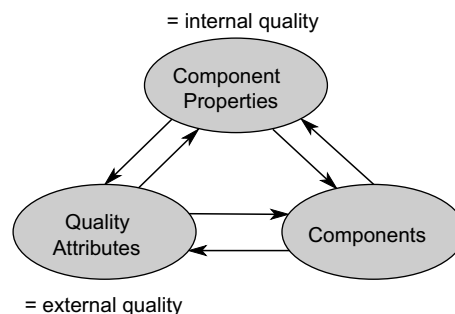


Fig. 6. Dromey's generic quality model [34].

- a set of components;
- a set of high level quality attributes;
- a set of tangible, quality-carrying properties of components.

Dromey's model is based on the relationships between *internal quality* (quality-carrying properties of products) and *external quality* (external manifestations of high-level quality attributes). He argues that the key to achieving quality software is through identifying empirical relationships between internal and external quality attributes.

3.5. Conclusion

As identified in Section 2, there is a lack of agreement on concepts and terminology in conceptual model quality research (Issue #5) and also a lack of consistency with the broader fields of software quality and quality management (Issue #6). We propose that researchers adopt a common vocabulary of concepts and terms based on ISO/IEC 9126 and that conceptual model quality frameworks⁶ should be structured in a similar way (see Box 2).

Box 2. Principles for structuring conceptual model quality frameworks (based on ISO/IEC 9126)

1. Conceptual model quality should be decomposed into a hierarchy of quality characteristics, subcharacteristics and metrics.
2. Single-word labels should be used for each quality characteristic and subcharacteristic, using commonly-understood terms.
3. Each quality characteristic and subcharacteristic should be defined using a single, concise sentence.
4. Metrics should be defined for measuring each subcharacteristic.
5. Evaluation process: detailed procedures should be defined for conducting quality evaluations.

While Dromey's approach defines an alternative basis for defining quality frameworks, ISO/IEC 9126 is preferable because it represents broad consensus among researchers and practitioners and is widely accepted and used in practice. Also, it is desirable that conceptual model quality frameworks are consistent with quality models used in later stages of the development lifecycle.

4. Development of quality frameworks

This section discusses possible approaches to developing conceptual model quality frameworks.

⁶ To be consistent with ISO/IEC 9126, conceptual model quality frameworks should probably be called *quality models* rather than *quality frameworks*, but the term "conceptual model quality model" is less clear.

4.1. Theory-based (deductive)

A number of conceptual model quality frameworks proposed in the literature have been developed based on theory, either from the IS field or from other disciplines. For example, [79] is based on semiotic theory while [15] is based on accounting principles. This is the most common approach for frameworks which have emerged from academic research. While it seems desirable to develop a framework which is soundly based on theory, there is no a priori reason why this is likely to be effective in practice.

4.2. Experience-based (codification)

Most of the frameworks which have emerged from practice have been developed based on experience. This usually involves expert practitioners generalising from their experience in practice and *codifying* their tacit knowledge about what makes a “good” conceptual model [28]. The limitation of this approach is that the resulting framework represents the subjective views and experiences of one or two people, which may be biased and have limited applicability to other people and contexts.

4.3. Observation-based (inductive)

Another possible approach to developing quality frameworks is to analyse conceptual modelling errors which occur in practice. Defects identified in quality reviews could be classified and used to build a hierarchy of quality characteristics (Fig. 7). Rather than building a *prescriptive* model in a top-down manner based on theory or experience (as in the first two approaches), this approach builds a *descriptive* model in a bottom-up manner based on observed defects. This might be considered a *grounded theory* approach [104], as the quality characteristics emerge from the data rather than being defined in advance. The advantage of this approach is that the resulting framework will automatically have a high level of empirical validity (Issue #2), provided a suitable

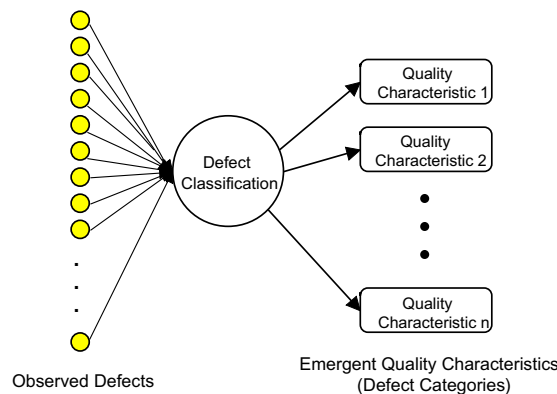


Fig. 7. Observation-based (inductive) approach.

number and variety of models are observed. While this approach has so far not been used in conceptual model quality research, it is probably the approach most commonly used in other disciplines (e.g. manufacturing [38], health care [136]). Analysis of conceptual modelling errors in practice would also provide valuable knowledge about relative incidence of errors and their impacts, which would help to address the current lack of knowledge about practices (Issue #12).

4.4. Consensus-based (*social*)

Another possible approach is to develop a quality framework based on consensus among experts in the field (conceptual modelling researchers and practitioners). Such a framework would reflect the “collective wisdom” of the field rather than the views of a single person or research group as in existing proposals. This was the approach used to develop ISO/IEC 9126 and UML. It is a long and arduous process to build consensus in this way and requires broad consultation to be successful, but would help to address the proliferation of proposals (Issue #1), lack of standardisation of concepts and terminology (Issue #5) and provided practitioners are sufficiently involved, practitioner acceptance (Issue #3). The reason why UML and ISO/IEC 9126 have achieved such widespread acceptance in practice is because they are seen to represent broad consensus among experts in the field. Previous software quality frameworks and OO modelling approaches proposed by individuals attracted small bands of devotees but not industry-wide acceptance: such a situation currently exists in the conceptual model quality field. While some might argue that such a process will not necessarily produce the best result—the need to incorporate so many people’s ideas (“design by committee”) could lead to a loss of conceptual integrity—it probably represents the best chance of developing a quality framework which will be widely accepted in practice.

4.5. Synthesis (*analytical*)

Another possible approach is to synthesise existing proposals into a unified conceptual model quality framework. This would help to address the problem of proliferation of proposals (Issue #1) and could provide the basis for a common paradigm in the field [67,72,133]. This approach was used with great success by deLone and McLean [29,30], who synthesised research on evaluating IS success to produce a consolidated model of IS success which has become the dominant paradigm in the field. This approach has been used to a limited extent in the conceptual model quality field where authors have integrated together two or more proposals (e.g. [25,116,139]), but has not yet been applied in a rigorous manner.

4.6. Derivation (*reverse inference*)

Given that there is an established standard for software quality, this could be used as a baseline for deriving an equivalent standard for conceptual model quality. This represents a process of *reverse inference*, as it involves working backwards from the quality characteristics of the final system (defined by ISO/IEC 9126) to the characteristics of the conceptual model required to achieve these characteristics (Fig. 8). This involves hypothesising causal relationships between

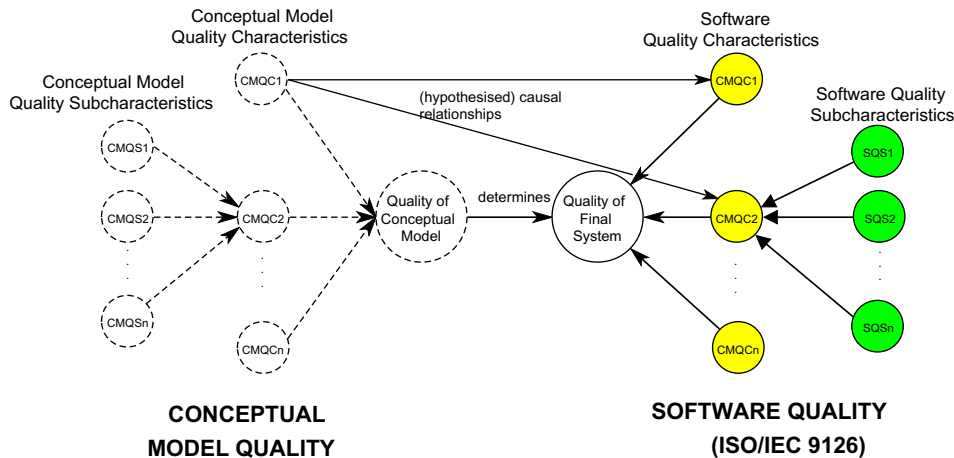


Fig. 8. Backward chaining (reverse inference) approach.

characteristics of the conceptual model (*internal quality*) and characteristics of the final system (*external quality*). In mathematical terms, this is analogous to solving an equation where the variables on one side are known but the variables on the other side are unknown. In Fig. 8, the variables on the right hand side are known, the variables on the right hand side are unknown but the two sets of variables are believed to be causally related. This approach has two major advantages:

- From a practical viewpoint, it would ensure consistency with ISO/IEC 9126 (Issue #6). It would also provide the basis for predicting the quality of the final system based on characteristics of the conceptual model [9].
- From a research viewpoint, the hypothesised relationships between conceptual model quality characteristics and software quality characteristics could be investigated empirically, which could provide insights into the relationship between internal and external quality.

4.7. Goal-Question-Metric (GQM) model

The Goal-Question-Metric (GQM) model is one of the most influential models for measurement and evaluation in the software engineering field [11,12]. It provides a way of developing measurement models in a top-down manner, starting with high level goals and working down to detailed metrics. The GQM model is not specifically focused on quality but has been proven to be useful in a variety of contexts. Its generality suggests it could be applied in conceptual model quality evaluation and could help to address some of the existing weaknesses in the literature:

- **Measurement:** it provides a structured approach to developing metrics, which is a clear weakness in the existing research (Issue #7).

- Improvement: it could also be used to define ways of improving quality, which is also a weakness in the existing research (Issue #9). Evaluation and improvement are simply two different *purposes* in the GQM model.
- Process quality: it could be used to develop a framework for evaluating conceptual modelling process quality, which is another weakness in the existing research (Issue #11). Product and process are simply different types of *objects* in the GQM model.

4.8. Dromey's methodology

Dromey [34] has defined a methodology for constructing product quality models, which complements his approach for structuring quality models (described in Section 3.4). This consists of five steps:

1. Identify a set of high-level quality attributes for the product (external quality attributes).
2. Identify the product components.
3. Identify tangible, measurable, quality-carrying properties for each component (internal quality attributes).
4. Propose relationships linking product properties and quality attributes.
5. Evaluate the model and refine it.

Dromey shows how this approach can be used to develop a quality framework for requirements specifications, which suggests that it could easily be adapted to conceptual models. This approach was used by Bansiya and Davis [9] to develop a quality framework for OO models.

4.9. Conclusion

This section has discussed a range of possible approaches to developing conceptual model quality frameworks (summarised in Box 3).

Box 3. Approaches to developing conceptual model quality frameworks

1. Theory-based (deductive).
2. Experience-based (codification).
3. Observation-based (inductive).
4. Consensus-based (social).
5. Synthesis (analytical).
6. Derivation (reverse inference).
7. Goal-Question-Metric model.
8. Dromey's methodology.

Most of the frameworks proposed in the literature have been developed using theory-based approaches (favoured by researchers) or experience-based approaches (favoured by practitioners). However some potentially promising approaches for the future are:

- Consensus-based: this could be used to build a quality framework which incorporates the collective knowledge of experts in the field. This would help to address the lack of consensus on concepts and terminology (Issue #5) and the issue of practitioner acceptance (Issue #3).
- Synthesis: this could be used to build a consolidated quality framework, which would help to address the problem of proliferation of proposals (Issue #1) and could form the basis for a shared paradigm in the field.
- Goal-Question-Metric model: this could be used to address weaknesses in the existing research with respect to measurement (Issue #7), quality improvement (Issue #9) and process quality (Issue #11).

5. Empirical validation of quality frameworks

5.1. The importance of empirical validation

One of the most weaknesses identified in the existing research is the lack of empirical testing (Issue #2). Empirical validation of conceptual model quality frameworks is important from both a research and practical viewpoint:

- Research: Empirical testing is one of the cornerstones of the scientific method and plays a critical role in validating research ideas. Conceptual model quality frameworks need to be tested empirically rather than being justified by logical arguments, theoretical argument, examples and anecdote evidence.
- Practical: Empirical testing can also be used to evaluate the practical efficacy of different proposals, and build up a reliable evidence base to inform practice [5,95]. This would help to resolve the current confusion for practitioners in deciding which of the competing proposals to use (Issue #1).

In more mature fields such as medicine, it is standard practice, even mandatory, to conduct empirical research to evaluate the efficacy of proposed new practices prior to advocating their use [27,112]. However in IS design research, it is often sufficient for researchers to argue on logical or theoretical grounds that their approach is effective [40,137].

There are a wide variety of research methods which may be used in conducting IS research [41,137]. Different research methods may be appropriate in different situations, depending on the research question and the state of knowledge in the area [40,64,75,89,104]. Here we review possible methods for empirically validating conceptual model quality frameworks (summarised in Box 4).

Box 4. Empirical validation approaches

1. Laboratory experiment: most powerful method for evaluating efficacy of frameworks and comparing frameworks.
2. Action research: way of testing and refining frameworks in real world settings.
3. Field experiment: theoretically the best method but difficult to apply in an IS context.
4. Survey: could be used to describe current practices and to build consensus on a common framework.
5. Case study: suitable for in-depth analysis of current practices.

5.2. Laboratory experiments

Laboratory experimentation is the most powerful research method for evaluating efficacy of quality frameworks, as it allows enables relatively objective evaluation using independent participants under controlled conditions. Because of the high level of control, it is possible to be reasonably certain that observed outcomes are attributable to the use of the framework and not some extraneous factor (internal validity) [8]. It also allows direct comparisons to be made between frameworks through manipulation of experimental treatments. In the medical field, double-blind experiments (*randomised clinical trials*) are considered to be the only permissible “evidence” that a treatment is effective [27,112]. Surprisingly, experiments are rarely used to evaluate the effectiveness of IS design methods: a review of IS design research over three decades found that only 1% of papers published were experiments [137].

Laboratory experiments were used to evaluate the effectiveness of the Lindland et al. [79] framework for evaluating the quality of process models [102] and data models [101]. The results were used to evaluate its reliability, validity, ability to accurately identify defects and likelihood of adoption in practice. A laboratory experiment was also used to test the Moody and Shanks [99] framework by using it to evaluate data models produced by experts and novices [115]. The results were used to evaluate its reliability, concurrent validity (ability to differentiate between expert and novice models) and interactions between quality factors. A laboratory experiment was used to evaluate the predictive validity of a set of OO quality metrics by investigating their ability to predict the quality of the final system [9]. Finally, a series of laboratory experiments were conducted to evaluate a set of complexity metrics for EER models, UML Class diagrams and UML Statechart models and their ability to predict maintenance effort [43–48,106].

The problem with most of the experiments conducted so far is that they have used undergraduate students as participants, which raises questions about their generalisability to practice (external validity) [42,67]. Generalisability is a problem in most experiments involving students, and has been identified as a major issue in IS research in its relevance to practice [42,67,91]. Another external validity issue is that the experimental tasks and models used are very simple compared to those used in practice. Finally, there have been no experimental comparisons of quality frameworks, even though this is something that experiments are ideally suited for and would provide valuable information for practitioners in choosing between the myriad of competing proposals (Issue #1). All experiments so far have been single group experiments evaluating a single framework in

isolation, without even a control group for comparison. Such designs are the weakest possible designs in terms of internal validity and are called *pre-experimental designs* [21].

5.3. Action research

Action research is a collaborative approach in which researchers work with practitioners to solve practical problems in field settings. It provides a way of testing and refining research ideas by applying them in practice [13,57,65,88]. Action research is conducted as a series of discrete *cycles*, which function as “mini-experiments” carried out in practice. Its major advantages are [7,23]:

- It allows research ideas to be tested in real world settings.
- It facilitates knowledge transfers between research and practice (Issues #3).
- It allows research ideas to be refined via an iterative learning process.

Action research was used to evaluate the Moody and Shanks [99] framework. The framework was applied in over 20 development projects over a two-year period and was refined significantly as a result [97]. Action research was also used to evaluate and refine a set of metrics for measuring quality of data models [92] and to develop a set of guidelines for improving quality of data models [94]. It has also been used to test and refine the Guidelines of Modelling (GoM) framework [16].

The limitation of action research as a validation approach is the lack of control, which means there will always be alternative explanations of outcomes (internal validity). It is impossible to be sure that use of the framework was responsible for the observed results and not some extraneous factor [7,13,24]. However given the difficulty of conducting field experiments in an IS context, it probably represents the most viable approach for testing quality frameworks in real world settings. Action research can be applied in field settings where more traditional experimental or quasi-experimental methods cannot easily be applied [33].

5.4. Field experiment

In theory, field experiments are the most effective way to validate conceptual model quality frameworks, as they overcome the internal validity problems of action research and the external validity problems of laboratory experiments. However field experiments are problematic to conduct in an IS context because of difficulties in persuading organisations to participate. So far there have been no field experiments conducted in this field.

5.5. Survey

Survey is a passive research method so is only suitable for evaluating existing practices [8]. Given that very few quality frameworks are currently being used in practice (Issue #3), a survey would reveal very little information about the effectiveness of different frameworks. Thus, given the current state of the field, survey research does not represent a viable validation approach. However a potentially useful application of survey research would be to describe current practices in evaluating quality of conceptual models, which would address the current lack of knowledge in

this area (Issue #12). Another potentially useful application of survey research is to build consensus on a common quality framework (Issue #1): this is discussed in Section 6.

5.6. Case study

Like survey research, case study is a passive research method so is not a suitable validation approach given the current state of the field. Action research, which is an active variant of case study, is much more suited at this stage. However case studies could be used to understand existing practices (Issue #12), and in more depth than would be possible using survey research [138]. For example, Maier [81] conducted case studies of conceptual modelling practices in a number of different organisations and used these to develop a quality management approach. A number of researchers have also applied their approaches to real projects to evaluate their predictive/concurrent validity and to gather information about quality of models in practice (e.g. [9,49,83,135]).

5.7. Conclusion

There has been little empirical research conducted in this field, especially in comparison to the number of frameworks proposed (normative research). Recommendations for future empirical research include:

- To conduct multiple-group, controlled ⁷ experiments to evaluate comparative effectiveness of different proposals, in order to provide guidance to practitioners as to which to use (Issue #1).
- To conduct experiments using practitioners and tasks of real world complexity to increase generalisability to practice.
- To evaluate the use of quality frameworks in real world settings. Action research probably provides the most viable approach for doing this and also provides the basis for improving frameworks and achieving technology transfer (Issue #3).
- To conduct research (surveys, case studies) to evaluate current practices in conceptual model quality to address this gap in our knowledge (Issue #12).

6. Achieving practitioner acceptance of quality frameworks

6.1. Crossing the rubicon: from research to practice

Up until now, none of the conceptual model quality frameworks proposed have been widely accepted in practice and few are currently in use. Consequently, despite the volume of research produced in this area, it seems to have had little or no impact on the quality of conceptual models in practice. Research knowledge is not intrinsically valuable: it only becomes valuable if it is used in practice [95,105]. This is what Denning [32] refers to as the difference between *invention* (a new

⁷ Using a control group for comparison, preferably using double-blind procedures.

idea) and *innovation* (the adoption of a new idea in a community). New ideas (inventions) have no impact unless they are adopted in practice (they become innovations):

“Invention means simply the creation of something new—an idea, an artifact, a device, a procedure. There is no guarantee that an idea or invention, no matter how clever, will become an innovation. . . Innovation requires attention to other people, what they value and will adopt; invention requires only attention to technology” [32].

Adoption of ideas is thus a *social* rather than an intellectual process. Academic research is primarily focused on the *production* of ideas rather than their *distribution* in practice [51]. Researchers have developed efficient mechanisms for disseminating knowledge among themselves through publication in scholarly conferences and journals, but little is known about how ideas are diffused in practice. There is little investment in the distribution of research results beyond communities of researchers, with the result that many ideas never find their way into practice. The issue of technology transfer is rarely addressed by researchers, and requires much more than publication in journals and conferences, which is normally seen as the endpoint of any research project [95].

One of the problems in the conceptual model quality field is that researchers and practitioners have worked largely in isolation, with practitioners publishing quality frameworks in practitioner books, trade journals and in-house quality manuals, and researchers publishing quality frameworks in textbooks, academic journals and conferences. This is symptomatic of the “cultural divide” which exists between IS research and practice [7]. Successful technology transfer depends on *two-way knowledge transfers* between research and practice rather than ideas flowing in only one direction [66]. This suggests the need for direct collaboration between the two groups. Action research provides a way of doing this, but only in a limited context i.e. in a single project or organisation at a time. As discussed in Section 4.4, perhaps the most effective way to achieve widespread adoption in practice is through the use of *consensus-based (social)* approaches. This recognises the social nature of the adoption/innovation process [32]. ISO/IEC 9126 and UML provide excellent examples of how such a process can be used to achieve widespread acceptance in the IT industry.

6.2. Where to begin?

In order to build consensus on a common framework, the first thing is to identify where to start. There are a number of possible starting points:

- Wait until the “right” framework is found. This seems to be the implicit assumption that researchers have been operating on up until now: that there is an ideal framework out there somewhere and once it has been discovered, consensus will occur automatically. The problem is that the process of generating new frameworks could go on forever.
- To start from scratch: to develop a quality framework from first principles based on input from researchers and practitioners. However this is contrary to the idea of building a cumulative tradition as it involves ignoring rather than building on previous research.
- Choose the “best” framework: one of the frameworks already proposed could be used as the basis for developing an agreed standard. This could be done by empirically testing the existing frameworks and determining which offers the best prospect of being successful in practice.

- Synthesise previous research: the existing proposals could be combined together to form a consolidated framework as described in Section 4.5. This supports the idea of a cumulative tradition as it explicitly incorporates all previous research. Also, from a social viewpoint, a consolidated framework is more likely to unify research efforts and attract broad-based support from researchers than choosing any one of the existing proposals. For these reasons, we argue that this provides the best starting point for developing consensus.

6.3. An international standard for data model quality

In this section, we describe a project in progress to develop an international standard for data model quality. Data modelling represents the most suitable starting point for developing a quality standard as this is where the research is most mature (or at least most numerous!); most of the proposals published so far have focused on static models (Issue #10). The project is being conducted in collaboration with the Data Management Association (DAMA), a non-profit professional association for data management practitioners. This is the leading professional association in the data management field, with around 7500 members in 40 chapters around the world www.dama.org. The purpose of the collaboration is to ensure the widest possible participation of data modelling practitioners in developing the standard.

The project consists of three phases (Box 5):

Box 5. Proposed approach to developing an international quality standard

1. Synthesise existing research to produce a consolidated quality framework.
2. Evaluate current practices and incorporate any new knowledge into the consolidated framework.
3. Use Delphi technique to achieve consensus between researchers and practitioners on a common quality framework.

Phase 1: Synthesis of existing research

The first phase of the project is to synthesise data model quality frameworks previously proposed in the literature into a consolidated framework (Issue #1). This follows the *synthesis* approach as described in Section 4.5. The consolidated framework will be structured using the principles defined in Section 3 (Box 2) and will consist of:

- a definition of data model quality;
- data model quality characteristics;
- data model quality subcharacteristics;
- data model quality metrics.

This will represent the *current state of research* in data model quality and will provide the starting point for developing a common standard.

Phase 2: Current practice assessment

The second phase of the project will gather information about current practices in data model quality. This will be done by surveying DAMA members, who represent a broad cross-section of data modelling practitioners, about their practices in evaluating quality of data models. This will describe the *current state of practice* in data model quality (Issue #12). Any new quality characteristics, subcharacteristics or metrics identified as a result of this assessment will be incorporated into the consolidated framework. The resulting framework will thus represent the *combined state of research and practical knowledge* in data model quality.

Phase 3: Expert consensus

The final phase of the project will be to achieve consensus among practitioners and researchers. The mechanism for doing this will be a *Delphi study*, a specialised form of survey which provides a way of achieving consensus over a series of rounds [58]. We propose using a modified Delphi study, conducted by email:

- In the first round, all participants will be sent the consolidated quality framework resulting from the first two phases of the project. They will be asked to give their feedback on this and suggest possible changes to it (e.g. adding, removing or modifying quality characteristics, subcharacteristics or metrics).
- In the second round, participants will be sent a revised quality framework which incorporates feedback from all participants in the first round. They will be asked to give their feedback on this framework and suggest possible changes to it.
- This process will be iterated for as many rounds as necessary to achieve convergence (measured by 80% agreement). Each round will incorporate the collective feedback of the participants in the previous round.

This process has a number of advantages over the typical standards development approach, which is based on face-to-face meetings:

- It is faster than face-to-face meetings, which are difficult to organise and can be slow and bureaucratic.
- It is more democratic: all participants have an equal say, which avoids the decision-making process being dominated by particular individuals or political agendas.
- It is more inclusive: a broad cross-section of researchers and practitioners can be involved in the process rather than just a “chosen few”, who may not be representative of the profession at large.
- It breaks down geographical barriers: use of email allows participants from all over the world to be involved.
- It is more “scientific”: the level of consensus can be measured using levels of convergence rather than determined subjectively.

To maximise acceptance of the resulting standard, participation of data modelling practitioners should be as wide and inclusive as possible. For this reason, *all* DAMA members will be invited to participate in the study. However participants will need to have a minimum of two years data

modelling experience to qualify for inclusion, to ensure that the standard is the result of *expert* consensus.

7. Conclusion

7.1. *The need for consensus*

For conceptual modelling to be considered as a legitimate discipline, consensus on a core body of knowledge is essential [1]. While a spread of opinions on different issues is healthy, there should at least be agreement on the fundamentals. One of the most basic issues in any discipline is to define what “quality” is: all members should share a common view of what constitutes good practice. Architects and engineers have agreed design standards [37], accountants have Generally Accepted Accounting Principles (GAAP) [52] and doctors have evidence-based medicine (EBM) guidelines [112]. All of these standards, principles and guidelines articulate what is good practice or “quality” in these fields. For conceptual modelling to progress from an “art” to an engineering discipline, quality standards need to be defined, agreed and applied in practice.

This paper has argued that the uncontrolled proliferation of quality frameworks is counterproductive to research progress [72,132]. It is also counterproductive for practice, as the number of competing proposals results in a tyranny of choice for practitioners. So far, the situation has been to “let many flowers bloom”, but this is the sign of an immature field. If the situation is allowed to continue, research will remain fragmented and practitioners will continue to use ad hoc and subjective approaches to evaluate models. For these reasons, we argue that developing a common quality standard should be an urgent priority for both researchers and practitioners in the conceptual modelling field. While it is possible that consensus on a common framework will emerge naturally over time, this seems highly unlikely as new frameworks continue to be proposed every year. While each proposal is likely to attract small bands of devotees (sometimes just the authors themselves!), it is unlikely that widespread consensus will emerge without a conscious effort to achieve it. ISO/IEC 9126 and UML did not happen by accident: these were the results of concerted efforts to develop common industry standards, and were successful in uniting research efforts and achieving widespread acceptance in practice. Researchers and practitioners need to work in collaboration to develop such a standard, rather than working in isolation as is currently the case.

In this paper, we have described some initial efforts towards developing an international standard for data model quality. This illustrates a novel approach to building consensus between researchers and practitioners, which provides a model for similar standardisation efforts.

7.2. *How many standards?*

While this paper has argued for the need for “a” common standard for conceptual model quality, it seems highly likely that multiple quality standards will be required. For example, there are fundamental differences between application-level models and enterprise-level models in how they are used (quality in use) [82]. Even at the level of different notations there are important differences which mean that different quality criteria are applicable (e.g. between ER models and

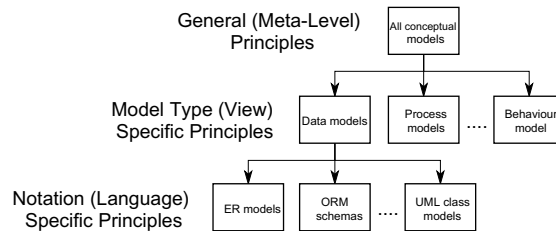


Fig. 9. Framework specialisation (GoM) [15].

ORM models [55]). This suggests that no single quality framework will be able to serve all purposes and that multiple quality frameworks will be needed for different types of models.

As discussed in Section 2, quality frameworks proposed in the literature are defined at different levels of generality: these represent different trade-offs between scope of application and practical applicability (Issue #4). A possible way of resolving this conflict is proposed in the Guidelines of Modelling (GoM) framework [15,16,113]. In this approach, a set of quality principles are defined at the top level that apply to all types of conceptual models. These are then expanded in more detail for different types of model (*views*), and in further detail for particular modelling notations (*languages*). This defines an *inheritance hierarchy* of quality frameworks (Fig. 9), which would allow a single standard to be defined at the highest level, which could be specialised or instantiated at multiple levels of detail.

7.3. Further research

This paper has identified a range of issues in conceptual model quality research and suggested some ways of addressing them. However in attempting such a broad review of the field, it has necessarily raised more questions than it has answered. Some of the issues which remain to be addressed are:

- Evaluation processes (Issue #8): Section 6 described a project to develop a data model quality framework, consisting of quality characteristics, subcharacteristics and metrics. The next step is to develop a *process* for applying this framework in a systematic way. This could be developed based on evaluation processes proposed in the data model quality literature [81,82,97,109] and the ISO/IEC software quality evaluation process (ISO/IEC 14598). Consensus on this process could be achieved in a similar way to the quality framework itself.
- Quality of dynamic models (Issue #10): notwithstanding the proliferation of quality frameworks, there is clearly a dearth of frameworks for evaluating quality of dynamic models. Such research has been hampered in the past by the lack of standardisation of process modelling notations, but the emergence of UML should largely address this. Section 4 suggests possible ways of developing such frameworks.
- Process quality (Issue #11): as discussed in Section 2, improving process quality is the most effective way to improve the quality of products [38]. While process quality is not explicitly addressed in this paper, having an agreed standard for product quality provides the first step towards improving process quality. A product quality framework can be used to classify errors

and identify patterns of errors (defect detection). This can be used to identify root causes of errors and to change processes to prevent them from occurring in the future (defect prevention). Over time, knowledge can be accumulated about the causes of different types of errors and how they can be prevented, which can be used to develop a framework for process quality.

References

- [1] A. Abran, J.W. Moore, P. Bourque, R. Dupuis, L.L. Tripp, *Guide to the Software Engineering Body of Knowledge (SWEBOK)*, Version 1.00, IEEE Computer Society Press, Los Amigos, CA, USA, 2001.
- [2] S. Allworth, Classification structures encourage the growth of generic industry models, in: D.L. Moody (Ed.), *Proceedings of the Eighteenth International Conference on Conceptual Modelling (Industrial Track)*, Springer, Paris, France, 1999, pp. 35–46.
- [3] F. Armour, G. Miller, *Advanced Use Case Modeling Volume 1: Software Systems*, Addison-Wesley, Reading, MA, USA, 2000.
- [4] P. Assenova, P. Johannesson, Improving quality in conceptual modelling by the use of schema transformations, in: B. Thalheim (Ed.), *Proceedings Of The Fifteenth International Conference On The Entity Relationship Approach*, Elsevier, Cottbus, Germany, 1996, pp. 227–244.
- [5] C. Atkins, G. Louw, Reclaiming knowledge: The case for evidence based information systems, in: *Proceedings of the 8th European Conference on Information System, ECIS2000*, Vienna, Austria, 2000.
- [6] D.E. Avison, G. Fitzgerald, *Information Systems Development: Methodologies, Techniques and Tools*, 3rd ed., Blackwell Scientific, Oxford, United Kingdom, 2003.
- [7] D.E. Avison, F. Lau, M. Myers, P.A. Nielsen, Action research, *Communications of the ACM* 42 (1) (1999) 94–97.
- [8] E.R. Babbie, *The Practice of Social Research*, 8th ed., Wadsworth Publishing, Belmont, CA, USA, 2003.
- [9] J. Bansiya, C. Davis, A Hierarchical model for object-oriented design quality assessment, *IEEE Transactions on Software Engineering* 28 (1) (2002) 4–17.
- [10] R. Barker, *Case*Method: Entity Relationship Modelling*, Addison-Wesley Professional, Wokingham, England, 1990.
- [11] V.R. Basili, G. Caldiera, H.D. Rombach, Goal question metric paradigm, in: J.J. Marciniak (Ed.), *Encyclopædia of Software Engineering*, Vol. 1, John Wiley & Sons, 1994, pp. 528–532.
- [12] V.R. Basili, H.D. Rombach, Tailoring the software process to project goals and environments, in: *Proceedings of the 9th International Conference On Software Engineering*, Monterey, CA, USA, 1987.
- [13] R.L. Baskerville, T. Wood-Harper, A critical perspective on action research as a method for information systems research, *Journal of Information Technology* 11 (3) (1996) 235–246.
- [14] C. Batini, S. Ceri, S.B. Navathe, *Conceptual Database Design: an Entity Relationship Approach*, Benjamin Cummings, Redwood City, CA, USA, 1992.
- [15] J. Becker, M. Rosemann, R. Schütte, Guidelines of modelling (GoM), *Wirtschaftsinformatik* 37 (5) (1995) 435–445 (in German).
- [16] J. Becker, M. Rosemann, C. von Uthmann, Guidelines of business process modeling, in: W.M.P. van der Aalst, J. Desel, A. Oberweis (Eds.), *Business Process Management: Models, Techniques and Empirical Studies*, Springer-Verlag, Berlin, 1999.
- [17] J. Becker, T. Rotthowe, M. Rosemann, R. Schutte, A framework for efficient information modeling: guidelines for retail enterprises, in: *Proceedings of the 3rd INFORMS Conference on Information Systems and Technology*, Montreal, Canada, 1998, pp. 442–448.
- [18] B.W. Boehm, *Software Engineering Economics*, Prentice-Hall, Englewood Cliffs, USA, 1981, p. 767.
- [19] B.W. Boehm, J.R. Brown, M. Lipow, Quantitative evaluation of software quality, in: *Proceedings of the 2nd IEEE International Conference on Software Engineering*, San Francisco, CA, USA, 1976, pp. 592–605.

- [20] G.J. Browne, V. Ramesh, Improving information requirements determination: a cognitive perspective, *Information & Management* 39 (2002) 625–645.
- [21] D.T. Campbell, J.C. Stanley, *Experimental and Quasi-Experimental Designs for Research*, Houghton Mifflin College, Boston, USA, 1963.
- [22] A. Chandra, R. Krovi, Representational congruence and information retrieval: towards an extended model of cognitive fit, *Decision Support Systems* 25 (1999) 271–288.
- [23] P.B. Checkland, From framework through experience to learning: the essential nature of action research, in: H.E. Nissen, H.K. Klein, R. Hirschheim (Eds.), *Information Systems Research: Contemporary Approaches And Emergent Traditions*, North-Holland, Amsterdam, Netherlands, 1991, pp. 397–403.
- [24] P.B. Checkland, S. Holwell, *Information, Systems and Information Systems: Making Sense of the Field*, John Wiley & Sons, Chichester, England, 1998.
- [25] S.S.-S. Cherfi, J. Akoka, I. Comyn-Wattiau, Conceptual modeling quality—from EER to UML schemas evaluation, in: S. Spaccapietra, S.T. March, Y. Kambayashi (Eds.), *21st International Conference on Conceptual Modeling, ER'2002*, Tampere, Finland, 2002.
- [26] S.S.-S. Cherfi, N. Prat, Multidimensional schemas quality: assessing and balancing analyzability and simplicity, in: D. Gentner, G. Poels, H.J. Nelson, M. Piattini (Eds.), *International Workshop on Conceptual Modeling Quality, IWCMQ'03*, Evanston, IL, USA, 2003.
- [27] A.L. Cochrane, *Effectiveness and Efficiency: Random Reflections on Health Services*, Royal Society of Medicine Press, London, 1972.
- [28] T.H. Davenport, L. Prusak, *Working Knowledge: How Organisations Manage What They Know*, Harvard Business School Press, Boston, Massachusetts, 1998.
- [29] W.H. de Lone, E.R. McLean, The deLone and McLean model of information systems success: A 10-year update, *Journal of Management Information Systems* 19 (4) (2003) 9–30.
- [30] W.H. de Lone, E.R. McLean, Information systems success: the quest for the dependent variable, *Information Systems Research* 3 (1) (1992) 60–95.
- [31] W.E. Deming, *Out of the Crisis*, MIT Center for Advanced Engineering, Cambridge, MA, 1986.
- [32] P.J. Denning, The social life of innovation, *Communications of the ACM* 47 (4) (2004) 15–19.
- [33] B. Dick, A beginner's guide to action research, in: B. Dick, R. Passfield, P. Wildman (Eds.), *Action Research and Evaluation On Line (AREOL)*, Available on-line at <http://www.scu.edu.au/schools/gcm/ar/arp/guide.html>, 2000.
- [34] R.G. Dromey, Cornering the chimera, *IEEE Software* 13 (1) (1996) 33–43.
- [35] R.G. Dromey, A model for software product quality, *IEEE Transactions on Software Engineering* 21 (2) (1995) 146–162.
- [36] C. Eick, A methodology for the design and transformation of conceptual schemas, in: G.M. Lohman, A. Sernadas, R. Camps (Eds.), *Proceedings of the 17th International Conference on Very Large Databases (VLDB)*, Barcelona, Spain, 1991, pp. 25–34.
- [37] A. Enders, H.D. Rombach, *A Handbook of Software and Systems Engineering: Empirical Observations, Laws and Theories*, Addison-Wesley, Reading, MA, USA, 2003.
- [38] J.R. Evans, W.M. Lindsay, *The Management and Control of Quality*, 6th ed., South-Western College Publishing (Thomson Learning), Cincinnati, USA, 2004, p. 848.
- [39] P. Fettke, P. Loos, Multiperspective evaluation of reference models: towards a framework, in: D. Gentner, G. Poels, H.J. Nelson, M. Piattini (Eds.), *International Workshop on Conceptual Modeling Quality, IWCMQ'03*, Evanston, IL, USA, 2003.
- [40] G. Fitzgerald, Validating new information systems techniques: a retrospective analysis, in: H.E. Nissen, H.K. Klein, R. Hirschheim (Eds.), *Information Systems Research: Contemporary Approaches And Emergent Traditions*, North-Holland, Amsterdam, 1991, pp. 657–672.
- [41] R.D. Galliers, *Information Systems Research: Issues, Methods and Practical Guidelines*, Blackwell Scientific Publications, 1992.
- [42] R.D. Galliers, Relevance and rigour in information systems research: some personal reflections on issues facing the information systems research community, in: *Proceedings of the IFIP TC8 Conference on Business Process Reengineering: Information Systems and Challenges*, Gold Coast, Australia, 1994.

- [43] M. Genero, L. Jiménez, M. Piattini, Measuring the quality of entity relationship diagrams, in: A.H.F. Laender, S.W. Liddle, V.C. Storey (Eds.), *Proceedings of the 19th International Conference on Conceptual Modeling, ER'2000*, Salt Lake City, UT, USA, 2000, pp. 513–526.
- [44] M. Genero, M.E. Manso, M. Piattini, G. Cantone, Building UML class diagram maintainability prediction models based on early metrics, in: *9th IEEE Symposium on Software Metrics (Metrics 2003)*, Sydney, Australia, 2003, pp. 263–275.
- [45] M. Genero, D. Miranda, M. Piattini, Defining metrics for UML statechart diagrams in a methodological way, in: D. Gentner, G. Poels, H.J. Nelson, M. Piattini (Eds.), *International Workshop on Conceptual Modeling Quality, IWCMQ'03*, Evanston, USA, 2003, pp. 118–128.
- [46] M. Genero, J. Olivas, M. Piattini, F. Romero, Assessing object oriented conceptual models maintainability, in: G. Poels, J. Nelson, M. Genero, M. Piattini (Eds.), *International Workshop on Conceptual Modeling Quality, IWCMQ'02*, Springer-Verlag, Tampere, Finland, 2002, pp. 118–128.
- [47] M. Genero, J. Olivas, M. Piattini, F. Romero, Knowledge discovery for predicting entity relationship diagram maintainability, in: *Proceedings of the 13th International Conference on Software Engineering and Knowledge Engineering, SEKE 2001*, Buenos Aires, Argentina, 2001.
- [48] M. Genero, J. Olivas, M. Piattini, F. Romero, Using metrics to predict OO information systems maintainability, in: *Proceedings of CAISE 2001*, Springer, Interlaken, Switzerland, 2001, pp. 388–401.
- [49] M. Genero, M. Piattini, C. Calero, An approach to evaluate the complexity of conceptual database models, in: *2nd European Software Measurement Conference, FESMA-AEMES 2000*, Madrid, Spain, 2000.
- [50] M. Genero, M. Piattini, C. Calero, Early measures for UML class diagrams, *L'Objet* 6 (4) (2000) 489–515.
- [51] M. Gibbons, C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, M. Trow, *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*, Sage Publications, Thousand Oaks, CA, USA, 1994.
- [52] J. Godfrey, A. Hodgson, S. Holmes, V. Kam, *Accounting Theory*, 3rd ed., John Wiley & Sons, New York, 1996.
- [53] R. Gray, B. Carey, N. McGlynn, A. Pengelly, Design metrics for database systems, *BT Technology Journal* 9 (4) (1991) 69–79.
- [54] T. Halpin, *Conceptual Schema and Relational Database Design: A Fact Oriented Approach*, Prentice Hall, Sydney, Australia, 1995.
- [55] T. Halpin, Entity relationship modeling from an ORM perspective, *Journal of Conceptual Modelling* (11) (1999).
- [56] T.A. Halpin, *Information Modelling and Relational Databases: From Conceptual Analysis to Logical Design*, Morgan Kaufman, San Francisco, 2001.
- [57] R. Hatten, D. Knapp, R. Salonga, Action Research: Comparison with the Concepts of the Reflective Practitioner and Quality Assurance, *Action Research Electronic Reader*, on-line, 1997.
- [58] O. Helmer, *Social Technology*, Basic Books, New York, 1966.
- [59] S. Hitchman, The entity relationship model and practical data modelling, *Journal of Conceptual Modelling* 31 (2004).
- [60] J.A. Hoxmeier, Typology of database quality factors, *Software Quality Journal* 7 (1998) 179–193.
- [61] ISO, *ISO Standard 9000-2000: Quality Management Systems: Fundamentals and Vocabulary*, International Standards Organisation (ISO), 2000.
- [62] ISO/IEC, *ISO/IEC Standard 9126: Software Product Quality*, International Standards Organisation (ISO), International Electrotechnical Commission (IEC), 2001.
- [63] ISO/IEC, *ISO/IEC Standard 14598: Software Product Evaluation*, International Standards Organisation (ISO), International Electrotechnical Commission (IEC), 1999.
- [64] T.D. Jick, Mixing qualitative and quantitative methods: triangulation in action, *Administrative Science Quarterly* 24 (1979) 602–611.
- [65] S. Jönsson, Action research, in: H.E. Nissen, H.K. Klein, R. Hirschheim (Eds.), *Information Systems Research: Contemporary Approaches And Emergent Traditions*, North-Holland, 1991.
- [66] H. Kaindl, S. Brinkkemper, J.A. Bubenko, B. Farbey, S.J. Greenspan, C.L. Heitmeyer, J.C.S.P. Leite, M.N.R.J. Myopolous, J. Siddiqui, Requirements engineering and technology transfer: obstacles, incentives and improvement agenda, *Requirements Engineering* 7 (2002) 113–123.

- [67] P.G.W. Keen, Relevance and Rigour in information systems research improving quality, confidence, cohesion and impact, in: H.E. Nissen, H.K. Klein, R. Hirschheim (Eds.), *Information Systems Research: Contemporary Approaches and Emergent Traditions*, Elsevier Science Publishers, North Holland, 1991.
- [68] S. Kesh, Evaluating the quality of entity relationship models, *Information And Software Technology* 37 (12) (1995).
- [69] J. Krogstie, Using a semiotic framework to evaluate UML for the development of models of high quality, in: K. Siau, T. Halpin (Eds.), *Unified Modeling Language: Systems Analysis, Design, and Development Issues*, IDEA Group Publishing, 2001, pp. 89–106.
- [70] J. Krogstie, H.D. Jørgensen, Quality of Interactive Models, in: G. Poels, J. Nelson, M. Genero, M. Piattini (Eds.), *International Workshop on Conceptual Modeling Quality, IWCMQ'02*, Springer-Verlag, Tampere, Finland, 2002.
- [71] J. Krogstie, O.I. Lindland, G. Sindre, Towards a deeper understanding of quality in requirements engineering, in: *Proceedings of the 7th International Conference on Advanced Information Systems Engineering, CAISE, Jyväskylä, Finland, 1995*.
- [72] T.S. Kuhn, *The Structure Of Scientific Revolutions*, University of Chicago Press, Chicago, USA, 1970.
- [73] S. Lauesen, O. Vinter, Preventing requirement defects, in: *Proceedings of the 6th International Workshop on Requirements Engineering: Foundation for Software Quality, REFSQ'2000*, Stockholm, Sweden, 2000.
- [74] J. Lechtenborger, G. Vossen, Multidimensional normal forms for data warehouse design, *Information Systems* 28 (2003) 415–434.
- [75] A. Lee, Integrating positivist and interpretivist approaches to organisational research, *Organisational Science* 2 (4) (1991) 342–365.
- [76] W. Lehner, J. Albrecht, H. Wedekind, Normal forms for multidimensional databases, in: *Proceedings of the 10th International Conference on Scientific and Statistical Data Management, SSDBM'98*, Capri, Italy, 1998.
- [77] M. Levene, G. Loizou, Why is the Snowflake Schema a good data warehouse design, *Information Systems* 28 (5) (2003) 225–240.
- [78] A. Levitin, T. Redman, Quality dimensions of a conceptual view, *Information Processing and Management* 31 (1) (1995) 81–88.
- [79] O.I. Lindland, G. Sindre, A. Sølvyberg, Understanding quality in conceptual modelling, *IEEE Software* 11 (2) (1994) 42–49.
- [80] R. Maier, Benefits and quality of data modelling: results of an empirical analysis, in: B. Thalheim (Ed.), *Proceedings of the Fifteenth International Conference on the Entity Relationship Approach*, Elsevier, Cottbus, Germany, 1996, pp. 227–244.
- [81] R. Maier, Evaluation of data modelling, in: J. Eder, I. Rozman, T. Welzer (Eds.), *Advances in Databases and Information Systems, ADBIS'99*, Maribor, Slovenia, 1999, pp. 232–246.
- [82] R. Maier, Organizational concepts and measures for the evaluation of data modeling, in: S. Becker (Ed.), *Developing Quality Complex Database Systems: Practices, Techniques and Technologies*, Idea Group Publishing, Hershey, USA, 2001.
- [83] S. Marche, Measuring the stability of data models, *European Journal of Information Systems* 2 (1) (1993) 37–47.
- [84] E. Marjomaa, Necessary conditions for high quality conceptual schemata: two wicked problems, *Journal of Conceptual Modelling* 27 (2002).
- [85] J. Martin, *Information Engineering*, Prentice Hall, Englewood Cliffs, NJ, USA, 1989, p. 3v.
- [86] J. Martin, *Information Engineering Book II: Planning and Analysis*, Pearson Education, 1990.
- [87] J.A. McCall, P.K. Richards, G.F. Walters, *Factors in Software Quality*, vols. 1–3, US Department of Commerce, Springfield, Virginia, USA, 1977.
- [88] G. McCutcheon, B. Jurg, Alternative perspectives on action research, *Theory into Practice* 24 (3) (1990) 153–172.
- [89] J. Mingers, Combining IS research methods: towards a pluralist methodology, *Information Systems Research* 12 (3) (2001) 240–259.
- [90] V.B. Misic, J.L. Zhao, Evaluating the quality of reference models, in: A.H.F. Laender, S.W. Liddle, V.C. Storey (Eds.), *Proceedings of the 19th International Conference on Conceptual Modeling, ER'2000*, Salt Lake City, UT, USA, 2000, pp. 513–526.

- [91] D.L. Moody, Building links between IS research and professional practice: improving the relevance and impact of IS research, in: R.A. Weber, B. Glasson (Eds.), *International Conference on Information Systems, ICIS'00*, Brisbane, Australia, 2000.
- [92] D.L. Moody, Measuring the quality of data models: an empirical evaluation of the use of quality metrics in practice, in: *Proceedings of the Eleventh European Conference on Information Systems, ECIS'2003*, Naples, Italy, 2003.
- [93] D.L. Moody, Metrics for evaluating the quality of entity relationship models, in: T.W. Ling, S. Ram, M.L. Lee (Eds.), *Proceedings of the 17th International Conference on Conceptual Modelling, ER '98*, Singapore, 1998.
- [94] D.L. Moody, Strategies for improving the quality of entity relationship models, in: *Information Resource Management Association (IRMA) Conference*, Idea Group Publishing, Anchorage, Alaska, 2000.
- [95] D.L. Moody, Using the world wide web to connect research and practice: towards evidence-based practice, *Informing Science Journal* 6 (2003).
- [96] D.L. Moody, G.G. Shanks, Evaluating and improving the quality of entity relationship models: an action research programme, *Australian Computer Journal* (1998).
- [97] D.L. Moody, G.G. Shanks, Improving the quality of data models: empirical validation of a quality management framework, *Information Systems* 28 (6) (2003) 619–650.
- [98] D.L. Moody, G.G. Shanks, What makes a good data model? A framework for evaluating and improving the quality of entity relationship models, *Australian Computer Journal* (1998).
- [99] D.L. Moody, G.G. Shanks, What makes a good data Model? Evaluating the quality of entity relationship models, in: P. Loucopoulos (Ed.), *Proceedings of the 13th International Conference on the Entity Relationship Approach*, Manchester, England, 1994, pp. 94–111.
- [100] D.L. Moody, G.G. Shanks, P. Darke, Evaluating and improving the quality of entity relationship models: experiences in research and practice, in: T.W. Ling, S. Ram, M.L. Lee (Eds.), *Proceedings of the 17th International Conference on Conceptual Modelling, ER '98*, Singapore, 1998.
- [101] D.L. Moody, G. Sindre, T. Brasethvik, A. Sølberg, Evaluating the quality of information models: empirical analysis of a conceptual model quality framework, in: L. Dillon, W. Tichy (Eds.), *Proceedings of the International Conference on Software Engineering, ICSE'2003*, Portland, USA, 2003.
- [102] D.L. Moody, G. Sindre, T. Brasethvik, A. Sølberg, Evaluating the quality of process models: empirical analysis of a quality framework, in: S. Spaccapietra, S.T. March, Y. Kambayashi (Eds.), *21st International Conference on Conceptual Modeling, ER'2002*, Tampere, Finland, 2002.
- [103] H.J. Nelson, D.E. Monarchi, K.M. Nelson, Ensuring the 'Goodness' of a Conceptual Representation, in: *Proceedings of the 4th European Conference on Software Measurement and ICT Control, FESMA'01*, Heidelberg, Germany, 2001.
- [104] W.L. Neuman, *Social Research Methods—Qualitative and Quantitative Approaches*, 4th ed., Allyn and Bacon, Needham Heights, MA, USA, 2000.
- [105] P.A. Phillips, Disseminating and applying the best evidence, *Medical Journal of Australia* (1998).
- [106] M. Piattini, M. Genero, L. Jimenez, A metric-based approach for predicting conceptual data models maintainability, *International Journal of Software Engineering and Knowledge Engineering* 11 (6) (2001) 703–729.
- [107] G. Poels, G. Dedene, Measures for assessing dynamic complexity aspects of object-oriented conceptual schemes, in: A.H.F. Laender, S.W. Liddle, V.C. Storey (Eds.), *Proceedings of the 19th International Conference on Conceptual Modeling, ER'2000*, Salt Lake City, UT, USA, 2000, pp. 513–526.
- [108] G. Poels, J. Nelson, M. Genero, M. Piattini, Quality in conceptual modeling—new research directions, in: G. Poels, J. Nelson, M. Genero, M. Piattini (Eds.), *International Workshop on Conceptual Modeling Quality, IWCMQ'02*, Springer-Verlag, Tampere, Finland, 2002.
- [109] M.C. Reingruber, W.W. Gregory, *The Data Modelling Handbook: a Best-practice Approach to Building Quality Data Models*, John Wiley & Sons, New York, 1994.
- [110] M. Rosemann, Managing the complexity of multiperspective information models using the guidelines of modelling, in: *3rd Australian Conference on Requirements Engineering, ACRE'98*, Geelong, Australia, 1998, pp. 101–118.

- [111] M. Rosemann, Preparation of process modeling, in: J. Becker, M. Kugeler, M. Rosemann (Eds.), *Process Management: A Guide for the Design of Business Processes*, Springer-Verlag, Berlin, Germany, 2003.
- [112] D.L. Sackett, W.S. Richardson, W. Rosenberg, R.B. Haynes, *Evidence Based Medicine: How to Practice and Teach EBM*, Churchill Livingstone, New York, 1997.
- [113] R. Schuette, T. Rothowe, The guidelines of modelling: an approach to enhance the quality in information models, in: *Proceedings of the 17th International Conference on Conceptual Modelling*, ER '98, Singapore, 1998.
- [114] R.B. Schwartz, M.C. Russo, How to quickly find articles in the top IS journals, *Communications of the ACM* 47 (2) (2004) 98–101.
- [115] G.G. Shanks, Conceptual data modelling: an empirical study of expert and novice data modellers, *Australian Journal of Information Systems* 4 (2) (1997).
- [116] G.G. Shanks, P. Darke, Quality in conceptual modelling: linking theory and practice, in: *Proceedings of the Pacific Asia Conference on Information Systems*, PACIS'97, Queensland University of Technology, Brisbane, Australia, 1997, pp. 805–814.
- [117] A.-W. Sheer, A. Hars, Extending data modelling to cover the whole enterprise, *Communications of the ACM* 35 (9) (1992) 166–172.
- [118] K. Siau, Informational and computational equivalence in comparing information modelling methods, *Journal Of Database Management* 15 (1) (2004) 73–86.
- [119] G.C. Simsion, *Data Modeling Essentials: Analysis, Design, and Innovation*, Van Nostrand Reinhold, New York, 1994.
- [120] G.C. Simsion, G.C. Witt, *Data Modeling Essentials: a Comprehensive Guide to Analysis, Design, and Innovation*, 2nd ed., The Coriolis Group, Scottsdale, Arizona, USA, 2000.
- [121] Standish Group, The CHAOS Report, in: The Standish Group International, Available on-line at http://www.standishgroup.com/sample_research/chaos_1994_1.php, 1994.
- [122] Standish Group, Unfinished Voyages, in: The Standish Group International, Available on-line at http://www.standishgroup.com/sample_research/unfinished_voyages_1.php, 1995.
- [123] W. Suryn, A. Abran, A. April, ISO/IEC SQuaRE. The second generation of standards for software product quality, in: *7th IASTED International Conference on Software Engineering and Applications*, Marina del Rey, CA, USA, 2003.
- [124] B. Teeuw, H. van den Berg, On the quality of conceptual models, in: S.W. Liddle (Ed.), *Proceedings of the ER-97 Workshop on Behavioral Modeling and Design Transformation: Issues and Opportunities in Conceptual Modeling*, Los Angeles, CA, USA, 1997.
- [125] B. Thalheim, *Entity Relationship Modeling: Foundations of Database Technology*, Springer-Verlag, Berlin, Germany, 2000, xii, 627.
- [126] H. van Vliet, *Software Engineering: Principles and Practice*, 2nd ed., John Wiley & Sons, New York, USA, 2000, p. 748.
- [127] R. Veryard, *Information Modelling: Practical Guidance*, Prentice-Hall, Englewood Cliffs, New Jersey, USA, 1992.
- [128] B. von Halle, Data: asset or liability? *Database Programming and Design* 4 (7) (1991).
- [129] C. von Uthmann, J. Becker, Guidelines of modelling (GoM) for business process simulation, in: B. Scholz-Reiter, H.-D. Stahlmann, A. Nethe, A. Noack, T. Bachmann (Eds.), *Process Modelling*, Springer-Verlag, Berlin, Germany, 1999.
- [130] C. von Uthmann, J. Becker, Managing complexity of modelling industrial processes with P/T nets, in: *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, San Diego, USA, 1998.
- [131] Y. Wand, R.A. Weber, Research commentary: information systems and conceptual modelling—a research agenda, *Information Systems Research* 13 (4) (2002) 363–376.
- [132] R.A. Weber, *Ontological Foundations of Information Systems* (Coopers And Lybrand Accounting Research Methodology Monograph No. 4), Coopers And Lybrand, Melbourne, Australia, 1997, p. 212.
- [133] R.A. Weber, Still desperately seeking the it artifact (editor's comments), *MIS Quarterly* 27 (2) (2003), iii–xi.
- [134] L. Wedemeijer, Defining metrics for conceptual schema evolution, in: H. Balsters, B. de Brock, S. Conrad (Eds.), *Database Schema Evolution and Meta-Modelling: 9th International Workshop on Foundations of Models and Languages for Data and Objects*, Dagstuhl Castle, Germany, 2001.

- [135] L. Wedemeijer, Long-term evolution of a conceptual schema at a life insurance company, in: M. Khosrow-Pour (Ed.), *Annals of Cases on Information Technology*, Idea Group Publishing, Hershey, USA, 2002, pp. 280–296.
- [136] R.M. Wilson, W.B. Runciman, R.W. Gibberd, B.T. Harrison, L. Newby, J.D. Hamilton, The quality in Australian health care study, *The Medical Journal of Australia* (1995).
- [137] J.L. Wynekoop, N.L. Russo, Studying systems development methodologies: an examination of research methods, *Information Systems Journal* 7 (1) (1997) 47–65.
- [138] R.K. Yin, *Case Study Research: Design and Methods*, 3rd ed., Sage Publications, Thousand Oaks, CA, USA, 2003.
- [139] V.Y. Yoon, P. Aiken, T. Guimaraes, Managing organizational data resources: quality dimensions, *Information Resource Management Journal* 13 (3) (2000) 5–13.
- [140] A. Zamperoni, P. Lohr-Richter, Enhancing the quality of conceptual database specifications through validation, in: R. Elmasri, V. Kouramajian, B. Thalheim (Eds.), *Proceedings of the 12th International Conference on the Entity Relationship Approach*, Dallas-Arlington, USA, 1993.
- [141] R.E. Zultner, The Deming Way: Total quality management for software, in: *Proceedings of Total Quality Management for Software Conference*, Washington, DC, 1992, pp. 134–145.



Daniel Moody is a Visiting Professor in the Department of Computer Science at the University of Iceland (visiting from the Gerstner Laboratory, Department of Cybernetics, Prague, Czech Republic). He has a PhD in Information Systems from the University of Melbourne and has held academic positions at Charles University (Prague), University of Maribor, Technical University of Valencia, Norwegian University of Science and Technology, Monash University, University of Melbourne, University of New South Wales and Queensland University of Technology. He has also held senior IT positions in some of Australia's largest commercial organisations, and has consulted at senior management level to a wide range of organisations in Australia and overseas. He is the current Australian President of the Data Management Association (DAMA) and Australian World-Wide Representative for the Information Resource Management Association (IRMA). He has published over 80 papers in the IS field, in both practitioner and academic forums, and has chaired a number of national and international conferences. His research interests include data modelling, UML, data warehousing, decision support systems, information economics, information architecture, medical informatics and IT education.