

A method for taxonomy development and its application in information systems

Robert C. Nickerson¹,
Upkar Varshney² and
Jan Muntermann³

¹Department of Information Systems, College of Business, San Francisco State University, San Francisco, California, USA; ²Department of Computer Information Systems, Robinson College of Business, Georgia State University, Atlanta, Georgia; ³Department of Information Systems and Department of Finance, Accounting and Taxes, University of Göttingen, Göttingen, Germany

Correspondence: R.C. Nickerson,
Department of Information Systems,
College of Business, San Francisco State
University, 1600 Holloway Avenue,
San Francisco, California 94132, U.S.A.
Tel: + 1-415-338-2138;
Fax: + 1-415-405-0364;
E-mail: RNick@sfsu.edu

Abstract

A fundamental problem in many disciplines is the classification of objects in a domain of interest into a taxonomy. Developing a taxonomy, however, is a complex process that has not been adequately addressed in the information systems (IS) literature. The purpose of this paper is to present a method for taxonomy development that can be used in IS. First, this paper demonstrates through a comprehensive literature survey that taxonomy development in IS has largely been *ad hoc*. Then the paper defines the problem of taxonomy development. Next, the paper presents a method for taxonomy development that is based on taxonomy development literature in other disciplines and shows that the method has certain desirable qualities. Finally, the paper demonstrates the efficacy of the method by developing a taxonomy in a domain in IS.

Keywords: taxonomy; typology; classification; taxonomy development; research methodologies

Introduction

A fundamental problem in many disciplines is the classification of objects of interest into taxonomies. Biology has studied this problem extensively and developed a number of classification schemes that order the complexity of the living world and provide a foundation for biological research. Similar schemes are also found in many social science fields. Taxonomies play an important role in research and management because the classification of objects helps researchers and practitioners understand and analyze complex domains. This universal character of taxonomies is also highlighted by Miller & Roth (1994, p. 286) who note that 'taxonomies ... are useful in discussion, research and pedagogy'.

The role of taxonomies is also well recognized in the information systems (IS) research literature. Glass & Vessey (1995) note that taxonomies provide a structure and an organization to the knowledge of a field, thus enabling researchers to study the relationships among concepts and, therefore, to hypothesize about these relationships. McKnight & Chervany (2001) argue that taxonomies can order otherwise disorderly concepts and allow researchers to postulate on the relationships among the concepts. Williams *et al* (2008) illustrate the use of taxonomies in understanding the science behind design principles of observed artifacts. Fiedler *et al* (1996, pp. 11–12) state that classification (i.e., taxonomy) has been important in research 'since Aristotelian applications over 2000 years ago'. Sabherwal & King (1995, p. 180) present a further argument by pointing out that 'taxonomies also help us understand divergence in previous research findings'.

From a philosophical foundations perspective, taxonomies are forms of conceptual knowledge in the epistemology of design science (Iivari, 2007), which also includes descriptive knowledge and prescriptive knowledge. As Iivari (2007, p. 46) explains 'The research goal at the conceptual level is essentialist: concepts and conceptual frameworks at this level aim at identifying essences in the research territory and their relationships'. Conceptual knowledge, including taxonomies, does not have a truth value but is relevant input for the development of theories representing forms of descriptive knowledge, which have a truth value (Iivari, 2007). Doty & Glick (1994) also argue that the classification of objects (i.e., taxonomy) contribute to theory building. This point is also stressed by Bapna *et al* (2004, p. 23), who state that 'a robust taxonomy can then be used to perform *ex post* theory building'.

Taxonomy is a form of classification, and, as discussed later, the terms, along with typology and framework, are sometimes used interchangeably. Wand *et al* (1995, p. 291) note that classification is 'a fundamental mechanism for organizing knowledge'. The systematic organization of knowledge is a long running concern in IS (Hirschheim *et al*, 1995). Ontologies have been proposed as one way of dealing with this concern and have found their way into IS (Guarino, 1998). Ontologies, defined by Gruber (1993) as explicit specifications of conceptualizations, can include a number of artifacts besides formal ontologies including thesauri, controlled vocabularies, folksonomies, and taxonomies (Gruninger *et al*, 2008). Often, however, these other artifacts – including taxonomies – are viewed as distinct from ontologies (Dogac *et al*, 2002), although Wand & Weber (2004) note that theories of ontology sometimes function like taxonomies. A taxonomy may be a step toward a future ontology, however, just as the periodic table, which can be viewed as a taxonomy of elements (Grove, 2003), was a step toward various ontologies in chemistry (Pinto & Martins, 2004). Although we focus on taxonomy development in this paper, ontology development is worthy of study in future research.

As we will show later in this paper, IS researchers have proposed a number of taxonomies over the years. In many cases, however, the development of these taxonomies has followed a largely *ad hoc* approach. Although the process of developing a taxonomy has been studied in a number of disciplines (e.g., Eldredge & Cracraft, 1980, and Sokal & Sneath, 1963, in biology; Bailey, 1994, in the social sciences), little has been written about this process in the IS field. Glass & Vessey (1995) note the lack of a taxonomy development methodology in their review of application-focused taxonomies. A well-conceived method for developing taxonomies would serve as a basis for developing new taxonomies in IS that could bring order to complex areas and potentially lead to new research directions. The general purpose of this paper is to present such a method.

Before creating a taxonomy development method, we need to examine how taxonomies are developed by other

researchers in IS. This paper presents a survey of IS literature that identifies common themes related to taxonomies and taxonomy development. On the basis of this literature survey, we define the problem of taxonomy development. This problem definition serves as a guide for the creation of the taxonomy development method described in this paper.

After creating a taxonomy development method we need to demonstrate its efficacy by applying it to specific domains. This paper uses the method to develop a taxonomy in one IS domain, that of mobile applications. We have chosen this domain because of its increasing importance and complexity with many new applications appearing regularly. Users, researchers, and developers need to be able to know where a new application fits with existing ones in this domain in order to determine if it is something entirely new and unique, a significant variation of an existing application, or just a retread of what we already have. A taxonomy provides a basis for making this determination and could point out voids where new applications might be developed.

Our research approach to creating a taxonomy development method is based on the design science research paradigm, which aims to address new knowledge about artificial (i.e., manmade) objects that are designed to meet certain goals and provide utility to their users (Simon, 1969). March & Smith (1995) present four kinds of contributions (artifacts) – constructs, models, methods, and instantiations – and two processes (research activities) – artifact building and artifact evaluation – that characterize design science research in IS. In this paper, we present a method that is intended to support design researchers during their research activities when developing a taxonomy for a specific domain. This method is an artifact that serves as a basis for future design science research, the purpose of which is to develop new taxonomies. These new taxonomies are artifacts (models) in themselves. In terms of research processes, we first build an artifact (method) for developing taxonomies. Then we evaluate the artifact we have built by using it to develop (i.e., build) a taxonomy that describes and classifies existing or future objects in a specific domain. Since the result of this second step is an artifact (taxonomy), it is subject to evaluation. We evaluate the taxonomy by assessing its efficacy in classifying objects of interest in the specific domain.

This paper is organized as follows. First, we define certain fundamental terms used in this paper. Then we discuss taxonomy development in other disciplines. Next, we present our literature survey and our analysis of the papers surveyed. Then we present our problem statement for creating a taxonomy development method. Following these topics, we present our method for developing taxonomies and justify it based on the foundation we have laid. Next, we demonstrate the use of our taxonomy development method by developing a taxonomy of mobile applications. We conclude the paper

with an extended discussion, summary of our results, and suggestions for future research.

Classifications, frameworks, typologies, and taxonomies

We are concerned with systems for grouping objects of interest in a domain based on common characteristics. We find that different terms are used for such systems, and that these terms are often confused. Before proceeding we need to clarify these terms and explain how we use them in this paper. We note that this is not an easy task, or, as Sokal & Sneath (1963, p. 2) say 'The adequate definition of taxonomic terms would almost require a book by itself'.

The term *classification* is used to refer to both the system or process of organizing objects of interest and the organization of the objects according to a system. Bowker & Star (1999, p. 10) use the term classification for 'a spatial, temporal, or spatio-temporal segmentation of the world' and the term classification system for 'a set of boxes (metaphorical or literal) into which things can be put to then do some kind of work'. Bailey (1994, p. 1) uses the term classification as the process of 'ordering entities into groups or classes on the basis of similarity'. He says that classification can be unidimensional or multidimensional, and that it can be done conceptually or empirically. Doty & Glick (1994), on the other hand, use the term classification scheme for a system that groups objects by applying specific 'decision rules'. In this paper, we use the term classification system for the abstract groupings or categories into which we can put objects and the term classification for the concrete result of putting objects into groupings or categories.

Framework is another general term used for organizing objects. In their paper on framework and review articles, Schwarz *et al* (2007, p. 41) implicitly define a framework in the context of framework articles as a 'set of assumptions, concepts, values, and practices that constitutes a way of understanding the research within a body of knowledge'. Their definition is closest to that of a classification system discussed above and could be used synonymously with it in some instances. They also provide 10 purposes of a framework article and 17 qualities of a framework within their context, many of which overlap our formal definition of taxonomy and our necessary conditions for a taxonomy to be useful that we discuss later in this paper. Interestingly, they also provide what we would call a taxonomy for framework and review articles with six dimensions.

The term *typology* is usually restricted to a system of conceptually derived groupings. Both Bailey (1994) and Doty & Glick (1994) use the term this way. Bailey also notes that typologies are usually multidimensional and distinguishes them from simple unidimensional classification systems, implying that typologies are usually more complex than classification systems.

The term *taxonomy* is perhaps the most confused. As with classification, taxonomy is sometimes used for

the system or process and sometimes used for the result of applying the system (Bailey, 1994). We could refer to the former as a taxonomic system and the later as a taxonomy, but we will follow the common practice of using the term taxonomy for both and allow the context to make it clear what we are referring to. In some literature, taxonomy is restricted to empirically derived groupings, often found through cluster analysis or some other statistical technique. This form of taxonomy is sometimes called numerical taxonomy (Sokal & Sneath, 1963). Doty & Glick (1994) equate taxonomy with classification scheme, although they note that classification scheme, taxonomy, and typology are often used interchangeably. Gregor (2006, p. 623) echoes this thought, stating that 'the term typology is used more or less synonymously for taxonomy and classifications'. Bailey (1994) distinguishes taxonomies (classification systems derived empirically) from typologies (classification systems derived conceptually). As we will see, however, Bailey presents a methodology for developing taxonomies/typologies that is a combination of conceptual and empirical approaches.

Much literature, however, uses taxonomy for systems of groupings that are derived conceptually or empirically. We make this observation in the literature survey discussed later in this paper. We also find in our literature survey that taxonomy is by far the most common term and thus we choose to use it throughout this paper whether we are referring to a conceptually or empirically derived grouping. We note that we could use any of the terms discussed here – classification, framework, typology, or taxonomy – for the object of study in this paper, and we recognize that in some situations taxonomy may not be the most precise term, but we opt for common recognition over precision in this paper and use taxonomy exclusively.

Taxonomy development in other disciplines

Developing a taxonomy is a complex process. Biology, with its well-known taxonomy of living organisms, provides some guidance. The traditional Linnaean taxonomy, commonly found in biology textbooks, classifies organisms based on a predefined hierarchy of categories from kingdom to species. Determining where a new organism falls in the taxonomy involves identifying into which classification the organism fits at each level of the hierarchy. However, biological taxonomy development is not limited to the traditional approach. Taxonomists also use phenetics and cladistics. *Phenetics*, sometimes called numerical taxonomy, involves classifying organisms solely on the basis of their similarity. The researcher identifies different characteristics of organisms and then uses statistical techniques to cluster the organisms into similar groups based on these characteristics (Sokal & Sneath, 1963). In contrast, *cladistics* does not look at common characteristics but rather examines the evolutionary relationships among organisms (Eldredge & Cracraft, 1980). The researcher investigates the evolution

of organisms from others and then groups organisms based on their evolutionary heritage. Two organisms may be closely related in a cladistic taxonomy because they have a common ancestor even though they do not share certain characteristics, thus putting them in different groups in a phenetic analysis.

Taxonomy development in the social sciences has also been well studied. Bailey (1994) provides a thorough survey of the subject. As noted previously, Bailey distinguishes between a typology and a taxonomy, saying that the former is derived conceptually or deductively and the latter is derived empirically or inductively. In the conceptual typology approach, the researcher proposes a typology of categories or *types* based on a theoretical ideal or model. In the process, the researcher could define an *ideal type*, which Bailey (citing Weber, 1949) explains is the 'extreme' or 'nirvana' of types. The ideal type is used to examine empirical cases in terms of how much they deviate from the ideal. Alternatively, in the empirical approach the researcher proposes a taxonomy based on a *constructed type*, which, as Bailey (citing McKinney, 1966) explains, is not the ideal but based on reference to empirical cases. The constructed type is used to examine 'exceptions' to the type. Bailey compares the ideal type with the highest value in a set of data (assuming highest is best) and the constructed type to the mean of the data (Bailey, 1994, p. 23).

In Bailey's conceptual approach, the researcher develops a typology starting with a conceptual or theoretical foundation and then derives the typological structure through deduction. The researcher may conceive of a single type and then add dimensions until a satisfactorily complete typology is reached, a process called *substruction* (Bailey, 1994, p. 24). Alternatively, the researcher could conceptualize an extensive typology and then eliminate certain dimension in a process called *reduction* (Bailey, 1994, p. 24) until a sufficiently parsimonious typology is reached.

The conceptual approach is not based on empirical data, although such data could be brought in toward the end of the process for verification purposes. The empirical approach, on the other hand, starts with data and derives the classification from this data using cluster analysis or other statistical methods (Bailey, 1994, p. 34). The goal is to find similarities among the data and to classify similar objects into the same category. Each category in the resulting taxonomy is called a *taxon* (plural *taxa*). Using the concepts from biology, this approach is phenetic.

Bailey (1984) describes the approaches just examined as different levels – conceptual and empirical – of a two-level model. Although researchers can approach classification through either level, he suggests that a common and often more useful approach is to use a three-level model that includes conceptual, empirical, and *indicator* or *operational levels*. In this method the researcher has two choices. One is to start with the conceptual approach and then to examine empirical cases

(conceptual to empirical) to see how they fit with the conceptualization. The other choice is to start with empirical data clusters and then to deductively conceptualize the nature of each cluster (empirical to conceptual). We note that in this three-level model Bailey combines typology development through conceptualization with taxonomy development through empirical data analysis to arrive at the final classification.

Survey of taxonomy development literature

In order to examine taxonomy development in IS, we conducted a literature survey of papers that have a focus on the development of taxonomies. As a basis for the literature survey, we used the AIS Journal Rankings page available from the AIS website (<http://ais.affiniscape.com/displaycommon.cfm?an=1&subarticlenbr=432>). From this ranking, we surveyed the top 30 journals and searched for papers that have the words taxonomy/ies or typology/ies in their title and that were published up to the year 2009. Further, we included papers published in *ICIS*, *AMCIS*, *ECIS*, *PACIS*, and *HICSS* proceedings. We identified 73 relevant papers that propose new taxonomies.

The AIS Journal Rankings focus on IS papers but also includes journals from computer science (CS) and non-information systems business (Bus) disciplines. We included papers in these closely related research fields to see how they compare. All papers surveyed are listed in the Appendix of this paper. We classified each paper by its principal domain: IS, CS, and Bus. We recognize that the line between IS and CS is sometimes not clear. For borderline cases, we classified a paper as IS if it emphasized the organizational/managerial aspects of the topic and as CS if it emphasized the technical aspects. Papers in e-commerce (including mobile commerce) were classified as IS. Bus papers include papers in marketing, operations, management, and other areas of business. The publishing journal also provided an indication of how to classify a paper. For example, ACM journals generally publish papers in CS and journals such as *EJIS*, *MISQ*, and *ISR* generally focus on IS research. We identified 41 IS papers, 20 CS papers, and 12 papers in Bus fields.

For each paper we noted the type of taxonomy it developed and the approach or method that the authors used for developing its taxonomy. We classified the approach into one of the following categories:

- Inductive
- Deductive
- Intuitive

The inductive approach involves observing empirical cases, which are then analyzed to determine dimensions and characteristics in the taxonomy. The analysis may be done using statistical techniques such as cluster analysis or may use less rigorous techniques; we noted this in our survey. This methodology is called phenetics

or numerical taxonomy in biology. Bailey (1994) calls this the empirical approach in sociology.

The deductive approach derives a taxonomy not from empirical cases but instead from theory or conceptualization. It identifies dimensions and characteristics in the taxonomy by a logical process derived from a sound conceptual or theoretical foundation. Cladistics in biology is similar to this approach. In sociology, Bailey (1994) identifies this as the conceptual approach. This approach may be followed by an analysis of empirical cases to evaluate and perhaps modify the taxonomy.

The intuitive approach is essentially *ad hoc*. The researcher uses his or her understanding of the objects to be classified to propose a taxonomy based on the researcher's perceptions of what makes sense. There is no explicit method in this approach.

Several other approaches were found that did not fall into these categories including morphological analysis and the use of existing taxonomies.

Table 1 shows the distribution of approaches used in the IS, CS, and Bus papers that we surveyed.

In a previous paper (Nickerson *et al*, 2010), we provide a detailed analysis of 65 papers. For the current research we excluded some papers that did not meet our selection criteria and identified additional papers that meet the criteria. The result is the 73 papers surveyed in this research. The ease with which we found a large number of papers that use the term taxonomy or typology in their titles indicates to us that there is interest in classification schemes in IS and the other fields examined.

Of the papers we found, 56 use the term taxonomy and 17 use the term typology. Overwhelmingly, the most common term used is taxonomy. However, there appears to be a great deal of confusion about what a taxonomy is. Some papers seem to use the word taxonomy to show that they are aware of the literature related to their problem area. They classify the literature into two or three simple categories, which may not completely define their domain. Other papers present lists as taxonomies, including lists of functions someone has to perform.

Published taxonomies range from very simple to complex. Some papers present simple $N \times N$ ($N = 2, 3, 4$) classifications. Most papers present taxonomies with four or fewer dimensions, but a few papers give taxonomies with more than 10 dimensions. There is no agreement on what represents an appropriate number of dimensions.

Many papers provide little information about the method the authors used to develop their taxonomies, so we could not identify the approach used in these papers. In fact, we classified over 40% (30) of the surveyed papers as not identifying the method used. In some cases, we were able to infer the method from other comments in the paper. When we could not, we interpreted these papers as using a purely intuitive approach based on the author's perception of what is a good classification for its intended purpose. We recognize that our interpretation may be incorrect in some instances. Several other papers were classified as using an intuitive

Table 1 Taxonomy development in different domains

Principal domain	Taxonomy development approach				
	Inductive (statistical analysis)	Inductive (informal analysis)	Deductive (may be followed by empirical verification)	Intuitive	Other
IS	7	10	9	13	2
CS	1	3	6	10	0
Bus	6	0	4	1	1
Total	14	13	19	24	3

approach. In total, we classified nearly one-third (24) of the surveyed papers as using an intuitive approach.

Many papers do not base their taxonomy on a conceptual, theoretical, or empirical foundation. Although authors review the literature in their problem area, their taxonomy is often not based on their literature review but instead is *ad hoc*. We classified these as using an intuitive approach.

Of the papers that use an inductive approach (27), about half (14) use statistical analysis to identify clusters appropriate for their taxonomy. The other half (13) use informal techniques to examine their empirical cases. Papers that use a deductive approach (19) were hard to identify. Some of the papers that we identified as using an intuitive approach may, in fact, use a deductive approach.

We could not find any relationship between the development method used and the term – taxonomy or typology – used for the final grouping. Although typologies are usually identified with a deductive approach and taxonomies with an inductive approach, this relationship was not evident in the papers we surveyed.

Papers in business tend to be more formal in their approach whereas papers in CS and IS tend to be less formal. Papers in the IS domain use the most diverse taxonomy development approaches.

Few papers cite the taxonomy development literature from other disciplines that we have identified.

A general conclusion from this survey is that many researchers in IS find taxonomies useful, and that a taxonomy development method that researchers can use in place of *ad hoc* methods may be beneficial.

Problem statement for taxonomy development

In this section, we state the research problem that we are exploring, that of defining a method for taxonomy development that can be used in the IS field.

To start we define what we mean by a taxonomy. A taxonomy T is a set of n dimensions D_i ($i = 1, \dots, n$) each consisting of k_i ($k_i \geq 2$) mutually exclusive and collectively exhaustive characteristics C_{ij} ($j = 1, \dots, k_i$) such that each object under consideration has one and only one C_{ij} for each D_i . Stated another way,

$$T = \{D_i, i = 1, \dots, n | D_i = \{C_{ij}, j = 1, \dots, k_i; k_i \geq 2\}\}$$

The mutual exclusive restriction means that no object can have two different characteristics in a dimension. The collectively exhaustive restriction means that each object must have one of the characteristics in a dimension. Together these conditions mean that each object has exactly one of the characteristics in each dimension.

We find a number of other terms used for dimension and characteristic. Sometimes dimension is called variable and the characteristics of a dimension are the possible values (domain) of the variable. This terminology is common in the cluster analysis literature (e.g., Anderberg, 1973; Aldenderfer & Blashfield, 1984). Sokal & Sneath (1963), in their foundational book on numerical taxonomy, use the terms taxonomic character and character state, which are standard terms in biology. Doty & Glick (1994) use attribute and value, respectively. Bailey (1994) uses dimension for typologies and variable for taxonomies. In our survey of the literature we found a variety of terms including category and capability, and characteristic and dimension with their meanings reversed. We choose to use dimension and characteristic as above because they are at least as common as others, they can apply to all forms of classification, and they are descriptive.

We want to develop useful taxonomies, but not necessarily 'best' or 'correct' ones, as these cannot be defined and, in fact, may be moving targets that could change over time. In the design science literature, this problem of not being able to find an optimal solution is described as *design as a search process*. As stated by Hevner *et al* (2004, p. 88), 'The search for the best, or optimal, design is often intractable for realistic information systems problems'. Instead, the search process attempts to discover effective – or useful – solutions. The taxonomy development literature gives us little help with metrics for evaluating taxonomies regarding effectiveness or usefulness. Indeed, Bailey (1994, p. 2) makes this clear when he repeatedly asks which of his example classifications is 'best' without giving guidance for finding the answer other than saying that 'a classification is no better than the dimensions or variables on which it is based'. Later, he lists 'weaknesses' of typologies including lack of mutual exclusivity and collective exhaustivity; lack of parsimony; lack of changeability (i.e., they are static); based on criteria that are arbitrary or *ad hoc*; and descriptive rather than explanatory (Bailey, 1994, p. 34). We note that we found these weaknesses in some of the proposed taxonomies surveyed previously. Bowker & Star (1999) also note the importance of mutual exclusivity in a classification system. In addition, they include completeness, in the sense of covering all objects in a domain, as an important property of a classification system.

Parsons & Wand (2008) propose that the ability to draw inferences is a critical condition for a useful classification, although not specifically a taxonomy. The authors define an inference as 'the ability to infer some properties of an instance by virtue of identifying it as a member of a class, without having to directly observe these properties'

(Parsons & Wand, 2008, p. 843). While this condition may be desirable for some uses of a taxonomy, it is not universally required. Many useful taxonomies have been developed that do not meet this condition, including, we contend, the Linnaean taxonomy of biology.

Without detailed guidance from the literature we are left on our own to define a useful taxonomy. We propose that a useful taxonomy has the following qualitative attributes:

- It is concise: A useful taxonomy should be parsimonious, for, as Bailey (1994) notes, lack of parsimony is a weakness. A taxonomy should contain a limited number of dimensions and a limited number of characteristics in each dimension, because an extensive classification scheme with many dimensions and many characteristics may exceed the cognitive load of the researcher and thus be difficult to comprehend and apply. We could state this attribute formally as a function of the number of dimensions and the number of characteristics that must have values less than maximums defined by factors including cognitive capacity in decision making. We leave this analysis for future research.
- It is robust: A useful taxonomy should contain enough dimensions and characteristics to clearly differentiate the objects of interest. A taxonomy with few dimensions and characteristics may not be able to adequately differentiate among objects. For example, a taxonomy with only one dimension and two characteristics within that dimension would not usually be useful. Bailey (1994, p. 1) makes this clear when he says that the goal is to 'make groups that are as distinct (non-overlapping) as possible, with all members within a group being as alike as possible'. This attribute can conflict with the conciseness attribute. As with the conciseness attribute, we could state the robustness requirement as a function of the number of dimensions and the number of characteristics that must have values greater than minimums needed to characterize the objects of interest. Again, we leave this analysis for future research.
- It is comprehensive: This attribute can be interpreted two ways. One interpretation is that a useful taxonomy can classify all known objects within the domain under considerations. This corresponds to Bowker & Star's (1999) requirement of completeness. Taxonomies that are developed empirically should display this attribute. The second interpretation is that a useful taxonomy includes all dimensions of objects of interest. Doty & Glick (1994, p. 294) imply this when, discussing ideal types in typologies, they say that 'typologies must provide complete descriptions of each ideal type using the same set of dimensions'. Taxonomies that are developed conceptually should display this attribute.
- It is extendible: A useful taxonomy should allow for inclusion of additional dimensions and new characteristics within a dimension when new types of objects appear. A taxonomy that is not extendible may soon

become obsolete. Put another way, it is dynamic, not static. Bailey (1994) points out that lack of changeability is a weakness.

- It is explanatory: A useful taxonomy contains dimensions and characteristics that do not describe every possible detail of the objects but, rather, provide useful explanations of the nature of the objects under study or of future objects to help us understand the objects. A taxonomy that simply describes objects may be of interest initially but will have little value in understanding the objects being classified. Bailey (1994) notes that typologies that are descriptive rather than explanatory are weak. This attribute allows a taxonomy to be used to identify where an object is found in the taxonomy or to identify the characteristics of an object found in the taxonomy. That is, if someone knows the characteristics of an object, he/she will find the object in an identifiable spot in the taxonomy, or if someone finds an object in a specific spot in the taxonomy, he/she will be able to identify the characteristics without having to know the complete details of the object.

These attributes form the necessary conditions for a taxonomy to be useful, but they do not necessarily identify the sufficient conditions. They can, however, give guidance to researchers and represent foundations that can be used for descriptive evaluations on the basis of informed argument by developing convincing arguments for a taxonomy's utility (Hevner & Chatterjee, 2010, p. 119). We are not able at this time to give sufficient conditions other than to say that a taxonomy is useful if others use it. Clearly, this condition is tautological. It is also correlated with design science research, which seeks utility, not truth (Hevner *et al*, 2004). If this is the only sufficient condition, however, then the only way to evaluate a taxonomy's usefulness is to observe its use over time. We would like to have sufficient conditions that are easier to apply than this condition and that could be applied before putting a taxonomy into use. However, such sufficient conditions are likely to depend on the expected use of a taxonomy. For example, one use of a taxonomy might be to help users navigate through a knowledge domain. A sufficient condition for this use might be related to how easy it is for the user to find related objects grouped together in the taxonomy. Another use might be to discover new things about a domain. In this case, a sufficient condition might be that some observations can be made about the domain that were not possible before. We could argue that the necessary conditions given previously are also sufficient but we feel that these conditions are not adequate for sufficiency. We leave this as an area for future research.

A taxonomy development method should have certain qualities. The goal of such a method is to develop a taxonomy with a set of dimensions each consisting of a set of characteristics that sufficiently describes the objects in

a specific domain of interest. The method should have the following qualities:

- It takes into consideration alternative approaches to taxonomy development. Because several approaches to taxonomy development are used, and no single approach has been determined to be 'best', any method must be flexible enough to allow for the selection of an approach or combination of approaches that is appropriate for the domain being studied.
- It reduces the possibility of including arbitrary or *ad hoc* dimensions and characteristics in the taxonomy. Any taxonomy should have dimensions and characteristics based on conceptual and/or empirical grounds. Arbitrary or *ad hoc* dimensions and characteristics should be avoided and a taxonomy development method must support this goal.
- It can be completed in a reasonable period of time. Any method must have a way of determining when it is finished. There must be an ending condition in the taxonomy development method that says when to stop, and this ending condition must be reachable in a reasonable amount of time.
- It must be straightforward to apply. Because taxonomies are developed by researchers with different levels of understanding of the taxonomy development literature, any method must be relatively easy to understand and apply without reference to the literature.
- It must lead to a useful taxonomy. Since our goal is to develop useful taxonomies, any method must accomplish this goal.

Our problem statement can thus be stated as follows: Define a method for developing taxonomies such that

- The resulting taxonomies satisfy the definition of a taxonomy given previously.
- The resulting taxonomies have the qualitative attributes listed previously.
- The method has the qualities listed previously.

Taxonomy development method

We now present our method for developing taxonomies of objects in a domain of interest. Following the design science paradigm, we are building an artifact that is a method, the purpose of which is to build (develop) another artifact (a taxonomy). Our method is intended to provide guidance for researchers during the design process of taxonomy development. We follow the definition of March & Smith (1995, p. 257), who define a method as a 'set of steps (an algorithm or guideline) used to perform a task'. Our method should provide a guideline to support the process of developing taxonomies in a domain of interest, that is, it should provide 'means to reach desired ends while satisfying laws in the problem environment' (Hevner *et al*, 2004, p. 88). For an earlier version of our method see Nickerson *et al* (2009).

Meta-characteristic

The development of a taxonomy involves determining the characteristics of the objects of interest. The choice of the characteristics in a taxonomy is a central problem in taxonomy development. The characteristics could be based on a theory but in reality any 'theory' is often implicit (Aldenderfer & Blashfield, 1984). The researcher must avoid, however, the situation of 'naïve empiricism' in which a large number of related and unrelated characteristics are examined in the hope that a pattern will emerge (Aldenderfer & Blashfield, 1984, p. 20). To avoid this situation and provide a basis for identifying the characteristics of the taxonomy, we specify a *meta-characteristic* at the beginning of the taxonomy development process. The meta-characteristic is the most comprehensive characteristic that will serve as the basis for the choice of characteristics in the taxonomy. Each characteristic should be a logical consequence of the meta-characteristic.

The choice of the meta-characteristic should be based on the purpose of the taxonomy. For example, assume that the researcher is trying to classify computer platforms (hardware and operating system) into a taxonomy. If the researcher's purpose is to distinguish platforms based on processing power, then the meta-characteristic is the hardware and software characteristics, such as CPU power, memory, and operating system efficiency that impact measures of power such as speed and capacity. On the other hand, if the researcher's purpose is to distinguish among computer platforms based on how users use them, then the meta-characteristic is the capability of the platform to interact with users, such as the maximum number of simultaneously running applications and the user interface.

The purpose of the taxonomy should, in turn, be based on the expected use of the taxonomy and thus could be defined by the eventual users of the taxonomy. The design process could involve first identifying the user(s) of the taxonomy who then specify the projected use of the taxonomy, either explicitly or implicitly. Explicitly, the potential use of a taxonomy could be elicited from actual users using elicitation techniques similar to those employed in requirements analysis (see, e.g., Goguen & Linde, 1993). Alternatively, the researcher could project who the users could be and decide, based on experience, what use the users could make of the taxonomy. In the computer platform example in the previous paragraph, the researcher may wish to develop a taxonomy to be used by customers purchasing computers (the users of the taxonomy). If the researcher projects that these customers will be technology-savvy individuals interested in processing power, then the first taxonomy would be appropriate. On the other hand, if the researcher determines that the customers will be application-savvy individuals interested in how they can use the computer, then the second taxonomy would be appropriate.

The choice of the meta-characteristic must be done carefully as it impacts critically the resulting taxonomy.

Although ideally the meta-characteristic should be specified before determining the characteristics in the taxonomy our experience has been that the meta-characteristic sometimes does not become clear until part way through the taxonomy development process when we ask ourselves what the overall 'theme' is of the characteristics that we have proposed. We have found that this exercise often leads to a clear statement of the meta-characteristic and to eliminating some characteristics and identifying new characteristics.

We see meta-characteristics appearing in research that develops taxonomies for various purposes, although they are not identified as such. For example, Nickerson (1997) develops a taxonomy of collaborative applications based on the meta-characteristic of communication among group members. Williams *et al* (2008) choose two meta-characteristics – design and objectives – in developing their taxonomy of digital services. Leem *et al* (2004) develop a classification scheme for mobile business models starting with the meta-characteristic of 'business players'.

Ending conditions

The method that we describe is iterative and thus must have conditions to determine when to terminate. These conditions are both objective and subjective. A fundamental objective ending condition is that the taxonomy must satisfy our definition of a taxonomy, specifically that it consists of dimensions each with mutually exclusive and collectively exhaustive characteristics. We have identified eight additional objective ending conditions listed in Table 2. Some of these conditions are adapted from Sowa & Zachman's (1992) rules for their IS architecture framework. This list is not exhaustive and future research may identify additional objective ending conditions. An initial step for the researcher is to decide which of these or other objective conditions will be used to determine when to terminate the method.

Subjective ending conditions also need to be examined. Previously, we noted that necessary conditions for a useful taxonomy are that it is concise, robust, comprehensive, extendible, and explanatory. These conditions are the minimal subjective ones that must be met for the method to terminate. Table 3 lists these subjective conditions with questions that the researcher could ask about each condition. The researcher can refer to the previous discussion of these conditions for further guidance. The researcher may wish to add more subjective conditions to these based on the researcher's particular view. The researcher needs to be able to argue that all subjective conditions have been met before terminating the method.

Depending on the chosen ending conditions, the method may generate somewhat different taxonomies, which is consistent with the design science philosophy of searching for useful, not necessarily optimal, solutions (Hevner *et al*, 2004). Our method can be extended to select a more useful taxonomy among multiple choices

Table 2 Objective ending conditions

<i>Objective ending condition</i>	<i>Comments</i>
All objects or a representative sample of objects have been examined	If all objects have not been examined, then the additional objects need to be studied
No object was merged with a similar object or split into multiple objects in the last iteration	If objects were merged or split, then we need to examine the impact of these changes and determine if changes need to be made in the dimensions or characteristics
At least one object is classified under every characteristics of every dimension	If at least one object is not found under a characteristic, then the taxonomy has a 'null' characteristic. We must either identify an object with the characteristic or remove the characteristic from the taxonomy
No new dimensions or characteristics were added in the last iteration	If new dimensions were found, then more characteristics of the dimensions may be identified. If new characteristics were found, then more dimensions may be identified that include these characteristics
No dimensions or characteristics were merged or split in the last iteration	If dimensions or characteristics were merged or split, then we need to examine the impact of these changes and determine if other dimensions or characteristics need to be merged or split
Every dimension is unique and not repeated (i.e., there is no dimension duplication)	If dimensions are not unique, then there is redundancy/duplication among dimensions that needs to be eliminated
Every characteristic is unique within its dimension (i.e., there is no characteristic duplication within a dimension)	If characteristics within a dimension are not unique, then there is redundancy/duplication in characteristics that needs to be eliminated. (This condition follows from mutual exclusivity of characteristics.)
Each cell (combination of characteristics) is unique and is not repeated (i.e., there is no cell duplication)	If cells are not unique, then there is redundancy/duplication in cells that needs to be eliminated

Table 3 Subjective ending conditions

<i>Subjective ending condition</i>	<i>Questions</i>
Concise	Does the number of dimensions allow the taxonomy to be meaningful without being unwieldy or overwhelming? (A possible objective criteria for this condition is that the number of dimensions falls in the range of seven plus or minus two; Miller, 1956.)
Robust	Do the dimensions and characteristics provide for differentiation among objects sufficient to be of interest? Given the characteristics of sample objects, what can we say about the objects?
Comprehensive	Can all objects or a (random) sample of objects within the domain of interest be classified? Are all dimensions of the objects of interest identified?
Extendible	Can a new dimension or a new characteristic of an existing dimension be easily added?
Explanatory	What do the dimensions and characteristic explain about an object?

and even merge multiple taxonomies into one if needed. We leave this for future research.

Taxonomy development method

We are interested in the characteristics of the objects being examined, not their evolutionary heritage. Thus, our approach to developing a taxonomy is phenetic, not cladistic. We find that Bailey's (1984) three-level indicator model provides a basis for a method for developing taxonomies as it offers alternative approaches that involve both conceptualization/deduction and empiricism/induction. Bailey, however, implies that taxonomy development takes one approach or the other – the 'classical strategy' of conceptual to empirical or the 'opposite strategy' of empirical to conceptual

(Bailey, 1994, pp. 31–32). Bailey's approach is also static in the sense that it terminates after applying one or the other strategy and does not cycle back for additional applications of the strategies. Thus, Bailey's approach is not consistent with the Hevner *et al* (2004, p. 88) design science research guideline that asks for 'design as a search process'.

Our method goes beyond Bailey's concept to combine the conceptualization/deduction and empiricism/induction strategies into a single method that encourages the researcher to use the strategies in an iterative manner to best reach a useful taxonomy. In addition, our method includes specific ending conditions that test the taxonomy as it is being developed. This approach is consistent with the design science 'generate/test cycle' described by

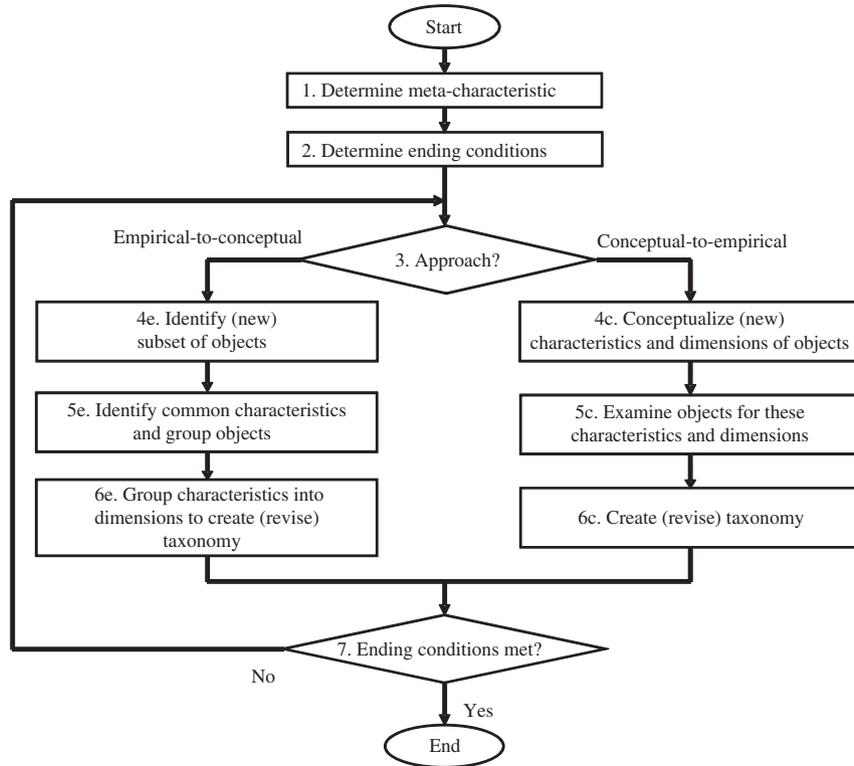


Figure 1 The taxonomy development method.

Hevner *et al* (2004, pp. 88–89). Finally, our method adds the important concept of meta-characteristic that Bailey does not identify explicitly or implicitly.

Figure 1 shows the method that we propose. Steps in this figure are numbered for later reference. A step-by-step explanation follows the figure.

The first step is to identify the meta-characteristic, which, as discussed previously, is based on the purpose of the taxonomy and in turn based on the users and their expected use of the taxonomy. Next, the conditions that end the process need to be determined. As discussed previously, there are both objective and subjective ending conditions. The researcher has a number of objective conditions that can be applied (Table 2). The subjective ones are the most difficult to identify and to apply. Table 3 provides initial guidance but the experience of the researcher will have an impact on the selection of subjective conditions. In the case of multiple researchers developing a taxonomy, various collaborative techniques, including the Delphi method, could be used to determine these conditions.

After these steps the researcher can begin with either an empirical approach or a conceptual approach. The choice of which approach to use depends on the availability of data about objects under study and the knowledge of the researcher about the domain of interest. If little data are available but the researcher has significant understanding of the domain, then starting with the conceptual-to-empirical approach would be advised.

On the other hand, if the researcher has little understanding of the domain but significant data about the objects is available, then starting with the empirical-to-conceptual approach is appropriate. If the researcher has both significant knowledge of the domain and significant data available about the objects, then the researcher will have to use individual judgment to decide which approach is best. In the fourth case, where the researcher has little knowledge of the domain and little data available, the researcher should investigate the domain of interest more before attempting to develop a taxonomy for it. In subsequent iteration the researcher may choose to use a different approach in order to view the taxonomy from a different perspective and possibly gain new insight about the taxonomy.

In the empirical-to-conceptual approach, the researcher identifies a subset of objects that he/she wishes to classify. These objects are likely to be the ones with which the researcher is most familiar or that are most easily accessible, possibly through a review of the literature. The subset could be a random sample, a systematic sample, a convenience sample, or some other type of sample. Next, the researcher identifies common characteristics of these objects. The characteristics must be logical consequences of the meta-characteristic. Thus, the researcher starts with the meta-characteristic and identifies characteristics of the objects that follow from the meta-characteristic. The characteristics must, however, discriminate among the objects; a characteristic

that has the same value for all or nearly all objects is of no use in the taxonomy even if it does follow from the meta-characteristic (Anderberg, 1973). The knowledge and intuition of the researcher or other experts will be needed to identify the characteristics. If multiple researchers or experts are working on the taxonomy, a group methodology, such as the Delphi method, could be employed. In the process, characteristics may be proposed that turn out not to be relevant and thus can be eliminated after further analysis.

Once a set of characteristics has been identified, they can be grouped formally using statistical techniques or informally using a manual or graphical process. The resulting groups form the initial dimensions of the taxonomy. This grouping involves creating 'conceptual labels' (Bailey, 1994, p. 32) for sets of related characteristics, that is, for the dimensions. Each dimension contains characteristics that are mutually exclusive and collectively exhaustive. For example, dimension D_1 may group characteristics C_{11} and C_{12} and dimension D_2 may group characteristics C_{21} , C_{22} , and C_{23} . All objects have one and only one of the characteristics C_{1j} in dimension D_1 and one and only one of the characteristics C_{2i} in dimension D_2 . Some dimensions may be dichotomous (e.g., D_1) and some may not be (e.g., D_2). This process is based on the (limited) empirical data that has been gathered about objects and the deductive conceptualization of the researcher. The result of this process is an initial taxonomy based on an empirical-to-conceptual approach.

In the conceptual-to-empirical approach, the researcher begins by conceptualizing the dimensions of the taxonomy without examining actual objects. This process is based on the researcher's notions about how objects are similar and how they are dissimilar. Since this is a deductive process, little guidance can be given other than to say that the researcher uses his/her knowledge of existing foundations, experience, and judgment to deduce what he/she thinks will be relevant dimensions. Each dimension contains characteristics that must be logical consequences of the meta-characteristic. Thus, a test of the appropriateness of a dimension is whether its characteristics follow from the meta-characteristic. In the process, the researcher may propose dimensions that are not appropriate and thus can be eliminated. The researcher then examines objects for these dimensions and characteristics. Are there objects that have each of the characteristics in each dimension? If not, then the dimension may not be appropriate. As before, each dimension must contain characteristics that are mutually exclusive and collectively exhaustive. The result of this process is an initial taxonomy based on a conceptual-to-empirical approach.

At the end of either of these steps, the researcher asks if the ending conditions have been met with the current version of the taxonomy. Both objective and subjective conditions must be checked. Since this is the first iteration, it is likely that none of the objective conditions will

be met so the process is repeated. In subsequent iterations the objective conditions must be evaluated and if not met, the process is repeated. If the objective conditions have been met, then the subjective conditions need to be examined. Evaluating these conditions requires the insight, experience, and skill of the researcher. Examples of heuristics that could be used were given previously. If all the subjective conditions have not been met, then the process is repeated.

In repeating the method, the researcher must again decide which approach to use. Since new objects may have been identified or new domain knowledge may have been obtained in the previous iteration, the researcher can use the previous heuristics anew to decide which approach to apply in the next iteration. In the empirical-to-conceptual case the researcher examines new objects to determine whether the existing characteristics are sufficient to describe them or if new characteristics and possibly new dimensions are needed. As before, statistical techniques can be used to aid in this process. This process could even result in the elimination of some dimensions and/or characteristics if they are determined not to be applicable. The result is the next version of the taxonomy. In the conceptual-to-empirical case the researcher reviews the previous taxonomy to try to identify additional conceptualizations that might not have been previously identified. In the process new characteristics may be deduced that fit into existing dimensions or new dimensions may be conceptualized each with their own set of characteristics. It may even be the case that some dimensions or characteristics are eliminated or combined so that fewer dimensions and/or characteristics result. The researcher examines empirical cases using the new characteristics and dimensions to determine their usefulness in classifying objects. The result is the next version of the taxonomy. As before, the researcher checks if the ending conditions (objective and subjective) have been met and either terminates the process or repeats it.

We note that with each iteration of the design process, new dimensions may be added and existing dimensions may be eliminated. These are the processes of subtraction and reduction, respectively, described previously and discussed by Bailey (1994, p. 24).

It is important throughout the process that the researcher remembers that the taxonomy must be explanatory, not descriptive. That is, it must contain dimensions and characteristics that do not describe objects in complete detail but, rather, provide useful explanations of the nature of the objects under study or of future objects.

Upon completion of the method (i.e., after the design science building phase), the resulting taxonomy needs to be evaluated for its usefulness (the design science evaluation phase). As we explained earlier, determining sufficient conditions for usefulness is difficult and evaluating usefulness may come down to seeing if others use it. Before this takes place, however, we can speculate

on potential use of the taxonomy. Given a user or users and the purpose of the taxonomy, can the user's purpose be satisfied with the taxonomy? To answer this question, we could query users about their potential use of the taxonomy, or if users are not available, we could evaluate what the taxonomy tells the users in relation to the purpose of the taxonomy.

We do not propose that our approach is the best or only taxonomy development method, only that it provides guidance during the process of taxonomy development. Further, it follows from the taxonomy development literature and satisfies the criteria listed previously in our problem statement. Specifically,

- It takes into consideration alternative approaches to taxonomy development. Our method uses both an empirical/inductive approach and a conceptual/deductive approach and allows the researcher to decide what approach to use at each pass through the method.
- It reduces the possibility of including arbitrary or *ad hoc* dimensions and characteristics in the taxonomy. Our method requires that the characteristics and dimensions be developed using a systematic process, not developed in an *ad hoc* way.
- It can be completed in a reasonable period of time. Our method is designed to reach closure in a few repetitions of the method, although this requires the insight of the researcher. If the researcher finds that the taxonomy is not converging on the ending conditions in each repetition of the method, then the researcher must take steps to rectify the situation, possibly starting again from scratch.
- It is straightforward to apply. Our method provides a specific set of steps that a trained researcher should be able to apply without additional reference to the taxonomy development literature.
- It leads to a useful taxonomy. This criteria is the hardest to determine if it has been satisfied. As discussed previously, a useful taxonomy must meet certain necessary conditions. The subjective ending conditions of the method include these conditions. These conditions, however, are not necessarily sufficient for a useful taxonomy. Unless more specific sufficient conditions can be identified, the only way to determine if the resulting taxonomy is useful is to observe its use by others over time. Asking users to evaluate the usefulness of a taxonomy is one way of evaluating the taxonomy. If a taxonomy turns out not to be useful, then the process needs to be restarted, perhaps with a different meta-characteristic.

Development of a taxonomy of mobile applications

To demonstrate the efficacy of the method described previously, we use it to develop a taxonomy of mobile applications. In the design science paradigm we are evaluating the artifact (method) built previously by using

it to develop another artifact, specifically a model, and evaluating that artifact (taxonomy) by using it to classify objects of interest. For less detailed discussions of the taxonomy developed here see Nickerson *et al* (2007) and Nickerson *et al* (2009).

We define a mobile application as a use of a mobile technology by an end-user for a particular purpose, for example, purchase a ring tone, check a weather forecast, transfer funds at a bank, make an airline reservation and so on. Mobile applications are provided by mobile services that have the infrastructure necessary to deliver the application. A mobile service, however, may provide several different applications under the umbrella of one service. For example, a mobile service may provide information about popular music and sell MP3 music files. For this paper, we view these as two different applications – one, an informational application, and the other, a transactional application – both provided by one service.

A number of taxonomies in the mobile/wireless area have been proposed. A review and critique of some taxonomies presented in the early stages of the mobile era and predominantly written in German can be found in Lehmann & Lehner (2002). More recent papers include Dombroviak & Ramnath (2007), which gives a taxonomy of what the authors call 'mobile pervasive' applications, Leem *et al* (2004) and Abdelaal & Ali (2007), which presents taxonomies of mobile business models, Nysveen *et al* (2005) and Heinonen & Pura (2006), which describe taxonomies of mobile services, Williams *et al* (2008), which gives a taxonomy of digital (not just mobile) services, Kemper & Wolf (2002), which presents a taxonomy dealing with mobile application development, and Dobson (2004), which gives a taxonomy of location in pervasive computing.

The users of the taxonomy we develop are researchers and developers of mobile applications. In characterizing mobile applications, this user group is interested in high-level characteristics of the user interaction with mobile applications. They are not interested in technical characteristics of the application, such as type of mobile device used or speed of network connection, nor in how the user uses technology, such as keypads and touch sensitive screens, with the application. Indeed, mobile technology is constantly evolving and any taxonomy based on it may quickly be out of date. In addition, this user group is not interested in characterizing the purposes of mobile applications, although developing a taxonomy with this goal may be beneficial. This user group wants to be able to use the taxonomy to identify the characteristics of how users interact with applications currently or may interact with applications in the future at a higher level of abstraction than the physical interaction with the application. Specifically, the purpose of our taxonomy is to distinguish among mobile applications based on how the application user interacts at a high level with the application. Such a taxonomy will help researchers and developers identify whether new applications are truly unique from the user's perspective

and where applications do not exist in the taxonomy suggesting opportunities for new applications. Thus, the meta-characteristic for the taxonomy development process is the high-level interaction between the user and the application.

We now demonstrate the application of the method shown in Figure 1 using the numbered steps in the figure.

- Step 1: Meta-characteristic: High-level interaction between the application user and the application.
- Step 2: Ending conditions: The method will end when both objective and subjective conditions have been met. For simplicity in this example, we will use only two objective ending conditions from Table 2, specifically, that no new dimensions are added in the last iteration and no additional applications need to be examined. Subjectively, the method will end when all the conditions in Table 3 are met, that is, when the taxonomy is determined to be concise, robust, comprehensive, extendible, and explanatory.

Iteration 1:

- Step 3: Approach: We decide to use the empirical-to-conceptual approach first because we have identified some mobile applications from previous research in the mobile area.
- Step 4e: We select the following convenience sample of mobile applications from the literature (Varshney & Vetter, 2002; Ngai & Gunasekaran, 2007):

- Mobile voice communications.
- Mobile messaging.
- Mobile TV.

- Step 5e: We identify the following user interaction characteristics in these applications based on our understanding of the applications and identify which application has each characteristic:

- User interacts with application synchronously.
- User interacts with application asynchronously.
- Information flows from the application to the user.
- Information flows from the user to the application and also from the application to the user.

For example, the mobile TV application involves synchronous user interaction and information flowing from the application to the user. All these characteristics follow from the

Table 4 Taxonomy of mobile applications after Iteration 1

<i>Applications</i>	<i>Temporal</i>		<i>Communication</i>	
	<i>S</i>	<i>AS</i>	<i>INF</i>	<i>INT</i>
Mobile voice communications	X			X
Mobile messaging		X	X	
Mobile TV	X		X	

meta-characteristic in the sense that they are aspects of the high-level user interaction with the application.

- Step 6e: Because the number of characteristics is small, we can group these characteristics manually into the following dimensions to form our first taxonomy:

- Temporal dimension: synchronous user interaction and asynchronous user interaction characteristics.
- Communication dimension: informational (information flows only from application to user) and interactive (information flows both from application to user and from user to application) characteristics.

In the notation used previously for our definition of taxonomy, our first taxonomy T_1 consists of dimension $D_1 = \text{Temporal}$ with characteristics $C_{11} = \text{Synchronous}$ and $C_{12} = \text{Asynchronous}$, and $D_2 = \text{Communication}$ with characteristics $C_{21} = \text{Informational}$ and $C_{22} = \text{Interactive}$, or more simply:

$$T_1 = \{ \text{Temporal (Synchronous, Asynchronous), Communication (Informational, Interactive)} \}$$

Table 4 shows the classification of the applications examined in this iteration in this taxonomy.

- Step 7: Ending conditions: Since two dimensions were created in this iteration, the method must be repeated. In addition, more mobile applications exist that need to be examined. We note, however, that the taxonomy is concise, extendible, and explanatory, but its limited number of dimensions and characteristics may not be robust, and it is not known if it is comprehensive because more mobile applications exist that need to be considered. At least one more iteration is needed.

Iteration 2:

- Step 3: Approach: We decide to use the empirical-to-conceptual approach again because we have

identified additional mobile applications from previous research in the mobile area.

Step 4e: We select the following sample of additional mobile applications from the literature (Varshney & Vetter, 2002 and Ngai & Gunasekaran, 2007):

- Purchasing location-based contents.
- Mobile inventory management.
- Product location and tracking.
- Mobile advertising.
- Mobile navigation.

Step 5e: We identify the following user interaction characteristics in these applications based on our understanding of the applications and identify which application has each characteristic:

- Information flows from the application to the user.
- User engages in a financial transaction through the application.
- User does not engage in a financial transaction through the application.

For example, the purchasing location-based contents application involves synchronous user interaction, information flowing from the application to the user, and the user engaging in a financial transaction. All these characteristics follow logically from the meta-characteristic.

Step 6e: We recognize that the first characteristic is an additional characteristic in the communication dimension identified previously. Thus, this dimension becomes:

- Communication dimension: informational (information flows only from application to user), reporting (information flows only from user to application), and interactive (information flows both from application to user and from user to application) characteristics.

The other two characteristics can be grouped into the following dimension:

- Transaction dimension: transactional (user engages in financial transaction) and non-transactional (user does not engage in financial transaction) characteristics.

At this point we have our second taxonomy:

$$T_2 = \{ \text{Temporal (Synchronous, Asynchronous)}, \text{Communication (Informational, Reporting, Interactive)}, \text{Transaction (Transactional, Non-transactional)} \}$$

Table 5 shows the applications examined so far classified in this taxonomy.

Step 7: Ending conditions: Since one more dimension was created in this iteration, the method must be repeated. In addition, more mobile applications exist that need to be examined. We note, however, that the taxonomy is concise, extendible, and explanatory, but its limited number of dimensions and characteristics may not be robust and it is not known if it is comprehensive because more mobile applications exist that need to be considered. At least one more iteration is needed.

Iteration 3:

Step 3: Approach: For the third iteration we decide to use the conceptual-to-empirical approach in order to get a different perspective on the taxonomy.

Step 4c: We conceive that some applications can interact with anyone, that is, they are public, and some applications can only be used by individuals who have certain privileges such as those who work for a company, that is, they are private. We identify this as an access dimension and note that it follows from the meta-characteristic:

Table 5 Taxonomy of mobile applications after Iteration 2

Applications	Temporal		Communication			Transaction	
	S	AS	INF	RP	INT	T	NT
Mobile voice communications	X				X		X
Mobile messaging		X	X				X
Mobile TV	X		X				X
Purchasing location-based contents	X		X			X	
Mobile inventory management		X		X			X
Product location and tracking		X	X				X
Mobile advertisement		X	X				X
Mobile navigation	X		X				X

- Access dimension: public (can be used by anyone) and private (use restricted to certain individuals) characteristics

Step 5c: We identify instances of these types of application. For example, purchasing location-based contents is a public application and mobile inventory management is a private application.

Step 6c: Adding this dimension to the previous three dimensions creates our next taxonomy:

$T_3 = \{ \text{Temporal (Synchronous, Asynchronous),}$
 Communication (Informational, Reporting, Interactive),
 Transaction (Transactional, Non-transactional),
 Access (Public, Private) $\}$

Table 6 shows the applications identified previously classified with this taxonomy.

Step 7: Ending conditions: Since one dimension was added in this iteration, we must repeat the method. The taxonomy is concise, extendible, and explanatory. However, the addition of another dimension makes the taxonomy more robust. At least one more iteration is needed.

Iteration 4:

Step 3: Approach: Since there are more applications to examine, we follow the empirical-to-conceptual approach for this iteration.

Step 4e: We select the following additional mobile applications from the literature (Varshney & Vetter, 2002; Ngai & Gunasekaran, 2007):

- Mobile games.
- Mobile entertainment services.
- Mobile social networking.
- Mobile communities.

Step 5e: We identify the following user interaction characteristics in these applications and identify which application has each characteristic:

- Application has a single user.
- Application has multiple users.

Although mobile applications can be used by many users simultaneously, users may not be aware of this characteristic and view their use of the application as individual. With some applications, however, users may know that they are part of a multiple-user community using the application.

Step 6e: We can group these characteristics manually into the following dimension to form our next taxonomy:

- Multiplicity dimension: individual (user experiences the application as if he/she were the sole user) and group (user views use of the application as part of a group) characteristics

At this point we have our next taxonomy:

$T_4 = \{ \text{Temporal (Synchronous, Asynchronous),}$
 Communication (Informational, Reporting, Interactive),
 Transaction (Transactional, Non-transactional),
 Access (Public, Private),
 Multiplicity (Individual, Group) $\}$

Table 7 shows all the applications identified so far classified in this taxonomy.

Step 7: Ending conditions: Since one more dimension was created in this iteration, the method must be repeated. We note, however, that the taxonomy is concise, extendible, and explanatory, and more robust than before. At least one more iteration is needed.

Table 6 Taxonomy of mobile applications after Iteration 3

Applications	Temporal		Communication			Transaction		Access	
	S	AS	INF	RP	INT	T	NT	PU	PR
Mobile voice communications	X				X		X	X	
Mobile messaging		X	X				X	X	
Mobile TV	X		X				X	X	
Purchasing location-based contents	X		X			X		X	
Mobile inventory management		X		X			X		X
Product location and tracking		X	X				X	X	
Mobile advertisement		X	X				X	X	
Mobile navigation	X		X				X	X	

Table 7 Taxonomy of mobile applications after Iteration 4

Applications	Temporal		Communication			Transaction		Access		Multiplicity	
	S	AS	INF	RP	INT	T	NT	PU	PR	I	G
Mobile voice communications	X				X		X	X		X	
Mobile messaging		X	X				X	X		X	
Mobile TV	X		X				X	X		X	
Purchasing location-based contents	X		X			X		X		X	
Mobile inventory management		X		X			X		X	X	
Product location and tracking		X	X				X	X		X	
Mobile advertisement		X	X				X	X		X	
Mobile navigation	X		X				X	X		X	
Mobile games	X				X	X		X			X
Mobile entertainment services	X		X			X		X		X	
Mobile social networking		X			X		X		X		X
Mobile communities		X			X		X	X			X

Iteration 5:

Step 3: Approach: We decide to use the conceptual to empirical because we feel that we can conceive new dimensions.

Step 4c: We conceive of two more dimensions of mobile applications with characteristics related to the meta-characteristic.

Some mobile applications may provide customized information or functionality based on the user's location, whereas other applications may not depend on where the user is located. The location dimension deals with whether the location of the user is used to modify the interaction of the application with the user:

- Location dimension: Location-based (application uses the user's location) and non-location-based (application does not use the user's location) characteristics

Like the location dimension, some mobile applications may adjust their information or functionality based on an awareness of who the user is, whereas other applications may not depend on the user's identity. The identity dimension relates to whether the identity of the user is used to modify the way the application interacts with the user based on the user's identity:

- Identity dimension: Identity-based (application uses the user's identity) and non-identity-based (application does not use the user's identity) characteristics.

Step 5c: We find a number of applications from our original lists with these characteristics. For example, mobile purchasing of location-based

content is location-based but mobile games are not, and mobile social networking is identity-based but mobile entertainment services are not.

Step 6c: Adding these two dimensions to the previous five dimensions gives us our next taxonomy:

$T_5 = \{$ Temporal (Synchronous, Asynchronous),
Communication (Informational, Reporting, Interactive),
Transaction (Transactional, Non-transactional),
Access (Public, Private),
Multiplicity (Individual, Group),
Location (Location-based, Non-location-based),
Identity (Identity-based, Non-identity-based) $\}$

All the applications are classified in this taxonomy in Table 8.

Step 7: Ending conditions: Since we added two dimensions in this iteration, we need to repeat the method. In addition, other applications need to be examined. The current taxonomy is concise, extendible, and explanatory, and the addition of two dimensions to a total of seven dimensions makes the taxonomy robust. It is not known if it is comprehensive because more mobile applications exist that need to be considered.

Iteration 6:

Step 3: Approach: Since there are more applications to examine, we follow the empirical-to-conceptual approach for this iteration.

Step 4e: We identify additional applications from the literature to consider (Varshney & Vetter, 2002; Ngai & Gunasekaran, 2007):

- Mobile auctions and financial services.
- Mobile distance education.
- Mobile ticketing.

Table 8 Taxonomy of mobile applications after Iteration 5

Applications	Temporal		Communication			Transaction		Access		Multiplicity		Location		Identity	
	S	AS	INF	RP	INT	T	NT	PU	PR	I	G	LB	NLB	I	NI
Mobile voice communications	X				X		X	X		X			X	X	
Mobile messaging		X	X				X	X		X			X	X	
Mobile TV	X		X				X	X		X			X		X
Purchasing location-based contents	X		X			X		X		X		X		X	
Mobile inventory management		X		X			X		X	X		X		X	
Product location and tracking		X	X				X	X		X		X			X
Mobile advertisement		X	X				X	X		X		X		X	
Mobile navigation	X		X				X	X		X		X			X
Mobile games	X				X	X		X			X		X	X	X
Mobile entertainment services	X		X			X		X		X		X			X
Mobile social networking		X			X		X		X		X		X	X	
Mobile communities		X			X		X	X			X		X		X

Table 9 Taxonomy of mobile applications after Iteration 6

Applications	Temporal		Communication			Transaction		Access		Multiplicity		Location		Identity	
	S	AS	INF	RP	INT	T	NT	PU	PR	I	G	LB	NLB	I	NI
Mobile voice communications	X				X		X	X		X			X	X	
Mobile messaging		X	X				X	X		X			X	X	
Mobile TV	X		X				X	X		X			X		X
Purchasing location-based contents	X		X			X		X		X		X		X	
Mobile inventory management		X		X			X		X	X		X		X	
Product location and tracking		X	X				X	X		X		X			X
Mobile advertisement		X	X				X	X		X		X		X	
Mobile navigation	X		X				X	X		X		X			X
Mobile games	X				X	X		X			X		X	X	
Mobile entertainment services	X		X			X		X		X		X		X	X
Mobile social networking		X			X		X		X		X		X	X	
Mobile communities		X			X		X	X			X		X		X
Mobile auctions and financial services		X			X	X		X			X		X	X	
Mobile distance education	X				X		X	X		X			X	X	
Mobile ticketing		X			X	X		X		X			X		X

Steps 5e and 6e: We cannot identify any new characteristics and dimensions from these applications. We group the new applications, along with the previous applications, using the existing characteristics and dimensions as shown in Table 9.

Step 7: Ending conditions: We have added no new dimensions with this iteration and we have examined a large sample of mobile applications. Hence, the objective ending conditions are met. The taxonomy is concise, extendible, robust, and explanatory. With the consideration of the additional applications, the taxonomy appears to be comprehensive. Thus, the taxonomy meets the subjective ending conditions. The method ends at this point.

Our final taxonomy of mobile applications is given in the previous formula (T_5) and listed here:

- Temporal dimension: Synchronous and asynchronous characteristics.
- Communication dimension: Informational, reporting, and interactive characteristics.
- Transaction dimension: Transactional and non-transactional characteristics.
- Access dimension: Public and private characteristics.
- Multiplicity dimension: Individual and group characteristics.
- Location dimension: Location-based and non-location-based characteristics.
- Identity dimension: Identity-based and non-identity-based characteristics.

As noted previously our goal is to create useful taxonomies. Our final test, then, is to examine the resulting

taxonomy for its usefulness for the intended users and the intended purpose. The users of the mobile applications taxonomy were projected to be researchers and developers of mobile applications, and their purpose was to distinguish among mobile applications based on how the application user interacts with the applications at a high level so as to help the taxonomy users identify the uniqueness of newly developed mobile applications and opportunities for new mobile applications. While the former goal cannot be tested until new applications appear, insight into the later goal can be gained by examining the taxonomy in Table 9. We can make several observations, including the following:

1. An approximately equal number of synchronous and asynchronous applications are identified in Table 9, implying that both modes have value. In the future, new applications could be developed that run in synchronous mode, but if network infrastructure is experiencing high traffic load, these applications could adjust to run in asynchronous mode.
2. Only one application in Table 9 is reporting, which may be because the current needs of users for reporting are being met by fixed devices. In the future, however, such requirements may move to mobile devices. Thus, more research and development could be done in designing mobile applications that have the reporting characteristic.
3. Most applications in Table 9 are non-transactional, which may be because financial transactions, such as online payments, are difficult with mobile devices. There may be opportunities for research and development into technology that facilitates mobile transactions, such as mobile payment systems.
4. Only two private applications are in Table 9, which could be because most mobile applications today are B2C with public access. There may be opportunities for research and development in mobile B2B or B2E applications, which would have private access.
5. Table 9 includes only four group applications, which means that there may be opportunities to develop new group applications.
6. Although there are fewer location-based applications than non-location-based applications in Table 9, the difference is small. Thus, both types of applications have value and future applications may be designed with either approach.
7. Identity-based and non-identity based applications are almost equally balanced in Table 9, implying that both types of applications may be developed in the future.
8. A number of voids can be found in the taxonomy. For example, there are no applications that have the combined characteristics of reporting, non-transactional, private, and group. An opportunity may exist for applications to fill this and other voids. For example, an application for older adults might be developed that allows users to report wellness and other information

about their lives to a group of geriatric friends who they may not be able to meet face to face.

Discussion

This paper has presented a method for taxonomy development that is based on the taxonomy development literature in other disciplines. The method is a hybrid of methods used for typology development (conceptual) and methods used for taxonomy development (empirical). The artifact resulting from applying our method can be thought of as a hybrid of a typology and a taxonomy. It could be called a classification, framework, typology, taxonomy, or some other term, although we have chosen to call it a taxonomy because our literature survey indicated that this term is the most commonly used one in papers that develop this type of artifact. By presenting a hybrid approach resulting in hybrid taxonomies, we are providing a method that results in taxonomies that are likely to be more broadly useful than those that come from more restricted approaches.

Our method does not identify an ideal type as is the expected result in traditional typology development. Likewise, our method does not result in a purely constructed type as in taxonomy development. Rather, our method takes a pragmatic approach to create an artifact that combines elements of both ideal and constructed types. We do not look at the effectiveness of individual elements classified in the taxonomy, as proposed by Doty *et al* (1993) in their discussion of ideal types and organizational configurations, but rather at the overall effectiveness of a resulting taxonomy to classify objects in a domain.

The flexibility of our method allows the researcher to develop taxonomies without the limitations imposed by traditional typology or taxonomy development. The artifacts resulting from our method are likely to be more comprehensive and more extendable (important characteristics of a useful taxonomy) than those resulting from traditional methods. Traditional typologies, with their emphasis on ideal types, may be less comprehensive and be harder to extend due to the difficulty in identifying ideal types. Traditional taxonomies, with their emphasis on constructed types, may also be less comprehensive and be difficult to extend due to their reliance on empirical cases. By combining the two approaches we allow the researcher to use a mixture that best serves the researcher's needs.

Our method is derived from the taxonomy development literature in other disciplines, most notably the social sciences. It follows from Bailey's (1984) 'three-level model' but goes significantly beyond that model by including alternative methods (conceptual to empirical and empirical to conceptual) that can be repeated in different combinations. The iterative nature of our method allows it to add/split and remove/merge dimensions and characteristics as it converges on an artifact that is at the same time concise and robust. Our method also includes the important concept of a meta-characteristic

and objective and subjective ending conditions, elements that are not found in Bailey's approach. Thus our method, while related to Bailey's, is different and a significant contribution to the research in taxonomy development.

Even with the method that we propose the judgment of the researcher is required. The selection of the meta-characteristic, the determination and application of the ending conditions, the decision of which path (empirical to conceptual or conceptual to empirical) to take at each iteration, the identification of object subsets, the conceptualization of characteristics and dimensions, and other steps in the method all require human judgment. Indeed, in some cases conflicting criteria may have to be resolved by the researcher, such as potential conflicts in the necessary criteria for a taxonomy to be useful. We have provided guidelines and heuristics to help the researcher, but these do not supplant the researcher's expertise and judgment. Some tools may help, such as statistical cluster analysis for the examination of empirical cases, but the researcher must make the final determination of the taxonomy's structure.

Researchers can use our method to develop taxonomies in different domains. Because the method is founded on established concepts about taxonomy development and has certain desirable qualities, researchers will have a high degree of confidence that taxonomies developed using this method will be useful to them and to others. We have demonstrated the use of the method in only one domain, but we have used it in other domains, and we are confident that the method can be applied in a wide range of domains.

We have proposed our method for use in developing taxonomies in IS and have illustrated it with an example from this discipline because it is the discipline with which we are most familiar. There is nothing unique in our method, however, to IS. Indeed, our problem statement for taxonomy development is not specific to IS, and no steps in our method apply only to IS. Investigation of the use of our method in other areas is a potentially fruitful area for future research. We speculate that this research is likely to indicate the general applicability of our method, and, if so, this may be the most significant contribution of this paper.

The implications of our method for researchers is that it provides an approach to taxonomy development that is neither intuitive nor *ad hoc*, as we found was the case in many papers that we surveyed, but rather deliberate and planned. Researchers can be reasonably confident that the taxonomies developed using our method will meet their needs if not exactly then at least closely. Readers of papers that present taxonomies developed using our method can also be reasonably confident that the taxonomy presented was developed in an established way.

Although we have presented only one example of the use of our method in taxonomy development in

this paper, we have used it to develop other taxonomies and to critique published taxonomies and typologies. We have also taught our method to other researchers who have used it to develop taxonomies for their research (Geiger *et al*, 2011; Krug *et al*, 2012). Continued efforts in these endeavors appear to be promising.

Summary and conclusion

This paper has examined the question of taxonomy development from several angles. First, it looked at a range of literature and concluded that, whereas many IS researchers have found taxonomies are useful, often the process of developing a taxonomy in IS is *ad hoc* (unlike taxonomy development in business or management-related outlets, which tend to use more formal approaches), and thus a method for taxonomy development that researchers can use in place of an *ad hoc* approach may be beneficial. Second, the paper defined the problem of taxonomy development, presenting necessary conditions for a taxonomy to be useful and requisite qualities of a taxonomy development method. Third, the paper presented a method for developing taxonomies based on well-established literature in taxonomy development and showed that the method had the requisite qualities. Fourth, the paper demonstrated the efficacy of the method by developing a taxonomy in an IS domain. The approach that the paper took followed the design science paradigm by first building a method for taxonomy development, then evaluating the method by using it to build a taxonomy (artifact), and finally evaluating the taxonomy by using it to classify objects in the domain.

The most important contribution of this paper is the method that we present for developing taxonomies. With this contribution we address the dichotomy of design science research, since our method supports design science researchers during their research activities (design as a process) in order to develop useful taxonomies (design as an artifact). Our method contributes to the knowledge base of IS research, that is, the scientific foundations from which it can be drawn when developing new taxonomies. The method addresses the process of taxonomy development and provides guidance during the design science build/evaluate cycle of developing taxonomies and evaluating them against a set of necessary conditions for usefulness.

Future research in taxonomies and taxonomy development in IS can take a number of directions. One is to investigate the question of sufficient conditions for a useful taxonomy, a question that was identified previously in this paper. Along with this question goes the question of whether a useful taxonomy has a minimal number of dimensions. Fundamental to the method we present in this paper is the concept of a meta-characteristic. How to determine the appropriate meta-characteristic for a taxonomy needs further investigation. Determining and applying ending conditions in our taxonomy development method requires some subjective

evaluation. Investigating ways that these conditions can be made more objective is worthy of further investigation. As we have noted, there is no one best taxonomy. We find further arguments for this in the design science foundations, which underline that the search for an optimal design is intractable. In fact, multiple taxonomies may be developed for a domain even when starting with the same meta-characteristic. How to compare different taxonomies for a given domain to determine which, if any, is best is an open question. The method that we present results in a single taxonomy. An alternative method would be to develop several, possibly overlapping taxonomies for different subsets of a domain. These taxonomies could come from a single researcher or from different researchers

About the authors

Robert C. Nickerson is a Professor of Information Systems at San Francisco State University and Chair of the Department of Information Systems from 2006 to 2012. His current research interests include taxonomies and taxonomy development in information systems, wireless/mobile systems, electronic commerce systems, and crowdsourcing. He has been a regularly invited professor at several European universities.

Upkar Varshney is an Associate Professor of CIS at Georgia State University, Atlanta. His current interests include mobile and wireless technologies, healthcare

technologies, pervasive computing, and m-commerce, and he has authored numerous papers. He chaired the International Pervasive Health Conference in 2006 and program chaired AMCIS in 2009.

Jan Muntermann is a Professor and Chair of Electronic Finance and Digital Markets at the Faculty of Economic Sciences, University of Göttingen. His research interests include decision support systems, design science and IT Governance, especially in the fields of E-Finance and Electronic Markets. His research has appeared in outlets such as Decision Support Systems and ICIS proceedings.

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Appendix

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