An Investigation Dimension for Understanding and Characterizing Computing Disciplines

Full Paper

Kwok-Bun Yue
University of Houston-Clear Lake
yue@uhcl.edu

Hisham Al-Mubaid
University of Houston-Clear Lake
hisham@uhcl.edu

Wei Wei
University of Houston-Clear Lake
wei@uhcl.edu

Abstract

Computing disciplines are diverse and overlap extensively. ACM provides two dimensions, theory and target level, as a tool to describe the problem spaces of five disciplines of computing: computer science, information systems, information technology, computer engineering, and software engineering. However, there are still many studies reporting that even majors are not entirely clear about the scopes and tasks of their computing disciplines. Various supplementary approaches and models have been proposed to assist the understanding and characterization of computing disciplines, such as through computing traditions, research-focuses, and positions in the business-technology continuum. This paper proposes a new *investigation dimension* based on a popular inquiry approach as a complementary third dimension to serve as an additional high order lens for understanding computing disciplines. The application of the model on understanding and characterizing the five ACM disciplines and data science is discussed. The model encourages systematic critical thinking, meaningful learning, and deep reasoning.

Keywords

Information Systems, Characterization, Computing Disciplines, 5W1H, Dimension, Investigation, Critical Thinking, Meaningful Learning.

Introduction: The Diverse Computing Disciplines

Computing have many disciplines and sub-disciplines. In 2005, the Association of Computing Machinery (ACM) started to define five main disciplines of computing and provided curriculum guidelines for each of them (ACM 2005). These five computing disciplines are Computer Science (CS), Information Systems (IS), Information Technology (IT), Computer Engineering (CE), and Software Engineering (SE). Likewise, ABET currently accredits degree programs of these five disciplines, with CS, IS, and IT usually under the Computer Accreditation Commission, and CE and SE under the Engineering Accreditation Commission (ABET 2017).

To illustrate the commonalities and differences among the computing disciplines, ACM developed a graphical view of their problem spaces (ACM 2005). The *theory dimension* runs horizontally from more theoretical on the left to more practical (application, deployment, and configuration) on the right. The vertical dimension, named the *target level dimension* here, describes the level of targeted concern and includes five levels from the bottom (the computer world) to the top (the people world):

1. Computer Hardware and Architecture
2. Systems Infrastructure
3. Software Methods and Technologies
4. Application Technologies

5. Organizational Issues and Information Systems

These two dimensions provide a graphical view of the problem spaces for characterizing the five computing disciplines. For example, Figure 1 shows the problem space for IS and CS respectively. In practice, the five computing disciplines have extensive overlaps (Courte & Bishop-Clark 2009) that are shown by the common areas of their corresponding problem space diagrams.

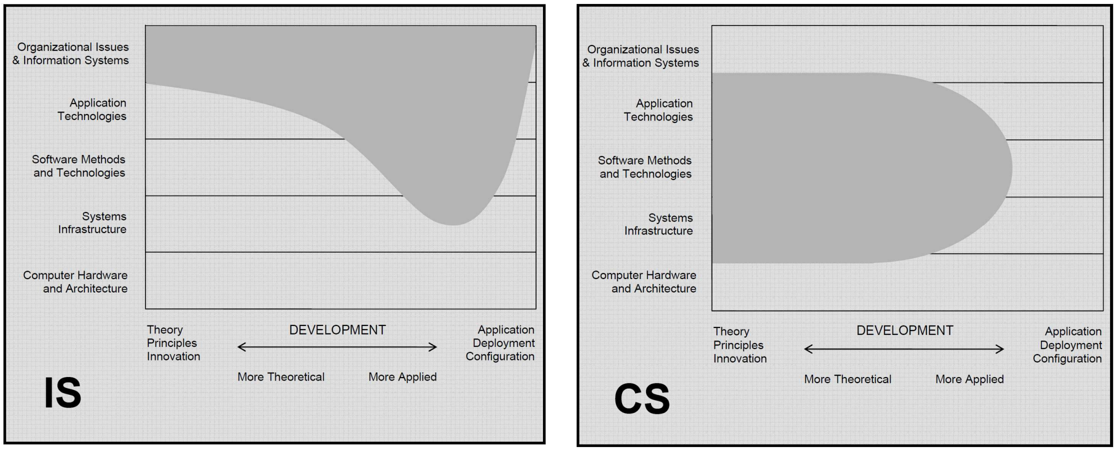

Figure 1. ACM's Problem Spaces for IS and CS (ACM 2005)

ACM went on to publish detailed information guidelines for each discipline: CS (ACM 2013), CE (ACM 2016), IS (ACM 2010), IT (ACM 2008) and SE (ACM 2014). These guidelines define the disciplines by the Body of Knowledge (BoK) of the program contents, expected learning outcomes, and required skills. They are invaluable resources to help universities in defining, building, and evolving their various computing degree programs. Their breadth and depth suggest that the guidelines are designed for domain experts, such as computing faculty members, and are thus much less accessible to laypersons. For example, it would be relatively difficult for general university-level academic advisors to use in counseling, or for freshmen to use in considering the various computing programs as their majors. There are a lot of complexity in the curriculum guidelines for the newcomers.

Past researches indicate that student understanding of computing disciplines can be inaccurate and incomplete. For example, Uzoka et al (2013) reported that computing majors are not always clear about the disciplinary fit of computing tasks, and the situation is worse for non-majors. The result is supported by Courte & Bishop-Clark (2009) in a survey of 375 students on identifying tasks in computing disciplines. The survey reveals that computing majors do not necessarily have a clear understanding of the scope of the disciplines. More importantly, students entering a computing field often have little understanding of their majors and the care ACM takes to differentiate the computing disciplines "does not filter to students who are making career choices. (Courte & Bishop-Clark 2009)" This result was further validated by Battig & Shariq (2011) using the same survey tool in smaller colleges. Consequentially, a panel moderated by Connolly called for "even clearer understanding of these sub-disciplines by the academic community, by guidance and career counsellors, and by, of course, prospective students" (Connolly, et al 2015).

In this paper, we propose an investigation dimension based on the Five W and One H (5W1H: who, what, where, when, why, how) inquiry approach. It can be used as a third dimension to provide another high level lens to understand the diverse computing disciplines, adding to the characterization by ACM and other researchers. The resulting model is simple and can be used for both experts and beginners to gain perspectives. The rest of the paper is organized as the following. Background literature review of related characterization efforts and 5W1H is provided in Related Work. In the section An Investigation Dimension, the proposed model is presented. Discussion on using the model in understanding and characterizing various computing disciplines is discussed in the two sections of Five ACM Disciplines and Data Science.

Related Work

Many attempts have been made in the past two decades to provide additional tools to understand and characterize different computing disciplines. Courte & Bishop-Clark (2009) identified the main task keywords to highlight the focus for each discipline to develop their survey tool: CS: theory; IS: business; IS: practical and applied; CE: hardware; SE: large-scale systems and projects. Anthony (2003) proposed three models that are based on a business-to-technology continuum dimension that bears some resemblances to the ACM target level dimension. The base model, the Computing Domain Continuum Model, classifies various disciplines in the technology/theory to business/management continuum from Electrical Engineering (EE), CE, CS, SE, IT, Computer Information Systems (CIS), IS, Management Information Systems (MIS) to IT Management (ITM). As expected, the three main variations of IS programs located closer to the business/management end. Vessey, Ramesh & Glass (2005) acknowledged the considerable overlap of computing disciplines and proposed a unified classification system by means of five research-focused characteristics: topic, approach, method, unit of analysis, and reference discipline. The system is probably more relevant to computing researchers. Tedre & Sutinen (2008) suggested that familiarity with the three traditions of computing, namely theoretical, scientific, and engineering, can provide students a balanced view of computing disciplines. In this paper, we propose an investigation dimension to supplement the existing literature.

The 5W1H Model

The Five W and One H (5W1H: who, what, where, when, why, how) is a well-known inquiry method of asking questions popularized by its use in journalistic reporting. It has since been adopted by many areas such as research, police investigation, and engineering for diverse purposes, such as problem solving (Wikipedia 2017). For example, 5W1H can be used as a technique for achieving Six Sigma, a popular disciplined and data-driven approach to eliminate defects (Mahalik 2017). The root of 5W1H model can be traced back to rhetorical questions in the middle ages (Copeland 1995). It provides a general investigation framework that appeals to many disciplines and subjects of investigation. For example, Shimazu et al (2006) proposed and tested a 5W1H-based metadata exchange interface for electronic interdisciplinary contents-sharing. Other examples in the computing areas include its use as models or investigation frameworks in diverse problem areas, such as CA5W1H Onto, an ontological context-aware model for wireless sensor network (Jeong-Dong, Son, Baik 2012), a model for incentive mechanism in mobile crowd sensing (Ma, Tao 2016), and an automated requirement determination and structuring approach (Jabar et al 2013). 5W1H has many variations in formulation and emphasis to facilitate its diffusion into different disciplines. These six questions are interrelated, and can be used to characterize disciplines. For example, Physics is the study of *what* the physical laws are, and *how* to use them to explain *why* things behave in certain ways.

An Investigation Dimension

Out of the questions in 5W1H, the more important questions are *what*, *how*, and *why* (2W1H). To simplify our model, we subsume the questions when, where, and who into the question what. For example, when deciding what mobile app to be built, it is important to consider what the people, times, and locations the app is expected to be used. Note that how the time, place, and person aspects are asked through a *what* question. This simplified model can provide a high level perspective of a discipline. For example, history is the study of what, how, and why historical events happened. These questions are investigative, related, and mutually supportive. A discipline should attempt to answer all of them. However, a discipline may also have one or more *primary* focal questions. For example, engineering is primarily concerned with *how* to build things, and natural sciences primarily care more about *why* things behave in certain ways.

For computing disciplines, we further adapt the 2W1H model to present an *investigation* dimension. Computing is ultimately about developing effective computer solutions to solve problems. Thus, we break down the what question to focus on two important but different areas: what should be done, and what technologies are available for us to use. As a result, four main investigative questions can and should be asked in constructing computer solutions.

1. What X: What X should be done? What applications X should be built? What decision X should be made?
2. What T: What are the theory and techniques of the available technology T? What will T be in the time frame of constructing and evolving the application X?
3. How X: How do we use T to design and develop an effective solution for X?
4. Why X: Why should X be done? Why do we want to build X?

To summarize, the what question is broken down into two what questions to form a 3W1H model as shown in in Figure 2. A computing project starts with what should be done (What X) with a sound justification (Why X). An effective solution (How X) is constructed based on the current and the expected future state of the technology (What T). These questions affect and interact with each other. The arrows in Figure 2 show the main interactions, which are bi-directional. For example, T is used to build X, but the demand of X also drives the advancement of T in return. Thus, the influence between What T and How X goes both directions. We can also ask the how and why questions on T too. However, there will then be too many questions to keep the model simple. Thus, we select to group all questions related to the theory and techniques of the technology in one question of what T.

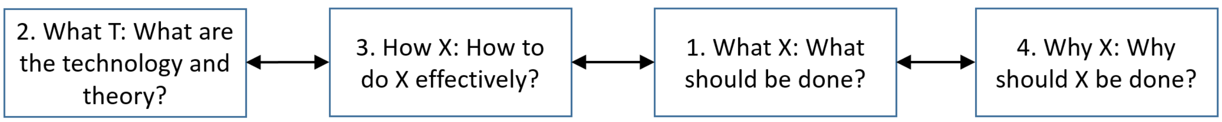

Figure 2. A 3W1H Investigation Model

Together, these inquiry questions form a complete investigation view of a project in the micro level, and a discipline in the macro level. An example on IS in the macro level will be discussed in the next section. As an example in the micro level, a start-up charity may want to build a mobile charity donation app. Possible answers to the questions in the 3W1H model are shown in Table 1.

Question	**Answer**
What X?	Build a multi-platform mobile app to track daily user exercise amount and link it to charity donation by sponsoring companies to a user-selected charity choice.
What T?	General mobile app development techniques, accelerometer, mobile payment, secure processing, database, cloud computing, etc.
How X?	Mobile app development, using payment technology for linking partner companies, Web server-side development, software modeling, software project management, etc.
Why X?	Enhance both personal good (exercising) and common good (charity donation); promote partner company images; collect user data for future app; etc.

Table 1. Possible answers for the 3W1H Model on a Charity Donation App

In the discipline level, each of these questions suggests different learning and research focus as shown in Table 2. Students with different aptitudes may identify the questions fitting their focal areas. For example, those who are interested in making building blocks for solving a variety of problems fit the focal area of What T, whereas those who like to use building blocks to make things fit How X more. In other words, system developers tend to focus more on What T and application developers tend to focus more on How X.

Question	Learning Focus	Research Focus
What X?	Understand and analyze a problem to make decisions and specify what to build to meet challenges and exploit opportunities.	Analysis, decision making, modeling, and specification.
What T?	Understand the state of the computing theory and techniques for problem solving.	Advance computing theories and techniques.
How X?	Construct effective computing solutions for specific problems.	Advance the theory and practice of the constructions of computing solutions.
Why X?	Understand the rationale behind a decision or why a computer application is desired.	Purpose, ethics, values, rationale of computing solutions, law, norms, etc.

Table 2. Learning and Research Focus

In conjunction with the two ACM dimensions, it can be seen that both What T and How X span the theory-practice spectrum of the theory dimension, as well as the Computer Hardware and Architecture level to the Application Technologies levels in the target level dimension. The What X question is related more to the Organization Issues and Information Systems level in the target level dimension, but goes beyond it since decision making, business or technical, may involve more than just organizational and IS issues. Using the charity donation app example, the charity start-up may actually be just a one-person charity venture using cloud computing as the platform. Thus, local organization and IS issues are less relevant in in deciding exactly what features to build. The Why X question does not fall neatly anywhere in the ACM problem space diagram. This lack of clear correlation with the two ACM dimensions is to be expected for a new dimension that is designed to be an independent lens.

The 3W1H investigation dimension places its focus on investigation for problem solving, instead of reporting, as in journalism. Thoroughly asking and answering the questions assists in effective problem solving. Thus, the investigation dimension may also be called the *problem solving* dimension. It encourages problem solving by systematic critical thinking, which is considered as one of the foundation knowledge and skills in many computing disciplines, including IS (ACM 2010). Critical thinking is associated with deep, meaningful learning in IS (Ausubel 1963, Wei & Yue 2016). Consider a popular critical thinking model by Paul and Elder (2012, 2007), which suggests that all thinking include eight encompassing Elements of Thought (EoT): purpose, question at issue, information, interpretation and inference (construction of solution), concepts (theory), assumption, implication and consequence, and point of view. Effective critical thinking means systematic thinking through the EoT using intellectual standards (such as clarity, accuracy, precision, relevance, depth, breadth, logic, significance, and fairness.) Although constructing a deep answer of any inquiry question includes all EoT, some are especially relevant to a specific investigation question, as shown in Table 3. Note that the EoT information is closely relevant to all questions and is thus not shown in Table 3.

Question	Elements of Thought
What X?	Purpose, Question at Issue, Point of View
What T?	Concepts (Theory), Interpretation and Inference (Solution)
How X?	Question at Issue, Interpretation and Inference (Solution)
Why X?	Purpose, Assumption, Implication and Consequence

Table 3. Main Elements of Thought in Critical Thinking

Five ACM Disciplines

Each inquiry question defines a focal area that can be used to understand and characterize computing disciplines. A discipline should answer all inquiry questions, but some focal areas may be more *primary* to a discipline. The relative importance of these focal areas may be considered as a macro level application of the proposed model to characterize computing disciplines. For example, ACM (2010) describes seven highest level *learning outcomes* for the IS curriculum:

1. Improving organizational processes
2. Exploiting opportunities created by technology innovations
3. Understanding and addressing information requirements
4. Designing and managing enterprise architecture
5. Identifying and evaluating solution and sourcing alternatives
6. Securing data and infrastructure
7. Understanding, managing and controlling IT risks

All four questions are relevant to each of the learning outcomes to different degrees. In particular, one can always ask the why question. Table 4 lists the questions that are most associated with these seven learning outcomes in the learning focus column. It also lists the relative amount of efforts the IS community put on the research focus on each question.

Question	**Learning Focus (ACM's outcomes)**	**Research Focus by IS Community**
What X?	[1], [3], [6], [7]	High
What T?	[2]	Low
How X?	[1], [2], [4], [5], [6]	High
Why X?	[3]	Very Low

Table 4. Learning and Research Focus of IS

Thus, it can be seen that What X and How X are the primary focal areas for IS. Table 5 lists the primary focal areas for the five ACM computing disciplines, as well as CIS, MIS, and Data Science. Among the sub-disciplines of IS, for MIS, deciding on what to do is more important, and thus What X ranks first, before How X. On the other hand, CIS focuses more on constructing information systems, and How X ranks first.

Discipline	**What X?**	**What T?**	**How X?**	**Why X?**
Information Systems	x		x	
Computer Information Systems	2		1	
Management Information Systems	1		2	
Computer Science		1	2	
Computer Engineering		2	1	
Software Engineering	2		1	
Information Technology			1	
Data Science	1			2

Table 5. Applying the Model on Different Computing Disciplines

The main concern of CS is to advance the theory and techniques of computing technology (What T) with a secondary concern of using this technology to construct solution (How X). The main focal areas of CE and SE are both practical: to construct solution (How X). Their domains of How X are different, though, as CE focuses on hardware, and SE focuses on large scale software projects (Courte & Bishop-Clark 2009). Their secondary concerns are also different. For CE, the emphasis on hardware to construct solutions means the advancement of related theory and technology is also very important (What T). On the other hand, the emphasis on large scale projects and effective processes in SE implies the importance of capturing and specifying problem requirements of the system to be developed (What X).

One contribution of this investigation dimension is its clear highlight of the relative lack of emphasis on Why X, especially in a deep level, in all five ACM computing disciplines as depicted by Table 5. It can be argued that IS emphasizes significantly more on Why X than the other four computing disciplines as the underlying rationale usually must be provided for sound decision making, a primary area for IS. Even so, the answer of Why X in IS seldom goes very deep. The reasons for building X or making a decision X in IS usually involve some combinations of maximizing profits, minimizing risks, embracing opportunities, and overcoming challenges for the company, and stop there without further probing. On the other hand, the why question is a very powerful one. The answer to a why question may open up another why question in a deeper level. In the charity donation app example, the main answer of the Why X question shown in Table 1 is "Enhance both personal good (exercising) and common good (charity donation)." One may then ask, for example, why does one want to enhance common good in this context? If the answer is that it feels good, then it involves values and morality that can be prompted further. If the answer is that it is a good way to make money, it is still a value and moral judgement eventually, and can thus also be questioned deeper. To answer a Why X question in a deeper level involves contemplation in many convoluted fields such as ethics, values, moral, law, norms, etc., as exemplified in Table 2.

It is not hard to see the reasons of the lack of emphasis on the why question. After all, computing is a technical and applicative discipline. Its theoretical and engineering tradition (Tedre & Sutinen, 2008) suggests an emphasis on What T and How X. The why question is an emphasis of the science tradition, the third tradition of computing. However, in computing disciplines, the usual focus of why is on the theory and techniques of the technology (Why T), and not the decision made (Why X).

On the other hand, the rapid advance of computing technologies results in possible quick development and deployment of inexpensive applications that can affect every aspect of our daily life. A local decision of an organization can have significant impact on the fabric of the entire society. It is more important than ever for profound contemplation on the deep rationale of computer solutions.

Data Science

As a further example, we apply the model on a nascent computing discipline: Data Science (DS). DS has become a very attractive career field rapidly within a few year (Davenport & Patil 2012, Donoho 2015, Glassdoor 2017, Mills, Chudoba, Olsen 2016), mostly due to the quick advance of Big Data (Royster 2013). Although Master of Science programs in Data Science and other similar titles can be offered by many different schools, they are by far most likely to be offered in business schools (Priestley 2017), usually as data analytics or business analytics degree programs or tracks.

The field and the subsequent characterization of DS is rapidly evolving, densely overlapping with other computing disciplines, and deeply inter-disciplinary (Mills, Chudoba, & Olsen 2016, Priestley 2017, De Veaux 2017). There are many attempts to define the topics in DS from many perspectives, such as six topics in Greater Data Science from the statistics perspective (Donoho, 2015), 18 topics from the Business Intelligence and Analytics perspective (Gupta, Goul, & Dinter 2015), and a curriculum guideline for undergraduate programs in DS (De Veaux 2017). A reasonable and concise attempt from the IS and Business Analytics perspective includes four main areas of topics (Kang, Holden, & Yu 2015): (1) Data preprocessing, storage, and retrieval, (2) Data explanation, (3) Analytical methods and algorithms, and (4) Data Product. There is an urgent need to better understand and characterize DS.

Characterizing DS by using the two ACM's dimensions may be more difficult, partially due to its highly inter-disciplinary nature that results in possible scattering in the problem space diagram. Furthermore, in the "more applied" end of the theory dimension, the description listed are "Application, Deployment, and Configuration" (Figure 1). In the current state, most DS programs and usages are practical and focused on analytics, and thus do not necessarily match well with this description. Furthermore, data in many DS projects are conceivably stored in the cloud, which may have an unclear position in the target level dimension.

It is conceivable to imagine that DS is closely associated with all four focal areas in our model. Currently, data analytics remain the basic focus of DS. Thus, the primary concern of DS is What X since Big Data business analytics is currently focused on identifying unknown correlations, hidden patterns, trends and preferences to make better business decisions. We argue that the second primary focal area for DS should be Why X (Table 5) not only to make up for its relative lack of emphasis by the other computing disciplines. More importantly, better decisions can only be made if we focus on their deep rationale.

Even more importantly, we now live in an age of DS and algorithms. Algorithms driven by DS increasingly affect every part of our daily lives. Important decisions in all areas, such as government and company policies, applications for credit, employment, school, etc. are made more and more by data-driven algorithms and models, instead of human being. These decisions have important and deep implications and consequences on many levels and areas that define the fabrics of our society, such as privacy, fairness, values, ethics, norms, law, etc. As critics of Big Data rightly pointed out, the algorithms and models used are often opaque and biased, potentially resulting in intrinsic discrimination, unfairness, inequality, etc. (O'Neil 2016). Individual decisions made by a company may have a small circle of influence. However, if most companies use similar approaches to make decisions, it canl have a large swarming effect on all aspects of our society that may result in many unexpected and possibly unpleasant consequences. The nascent DS discipline is a good opportunity for us to call to attention on the focal area of Why X. Companies using DS should not only have maximizing short-term profits in mind, but should also understand the longer-term, larger scale implications on the society, which will in turn affect the long term viability of the business. Accordingly, DS degree programs may consider adding relevant courses beyond usual theory, techniques, and domain-specific DS courses.

Conclusion

In this paper, we propose a third dimension, the investigation dimension, for understanding and characterizing computing disciplines to supplement existing approaches. We use the model to discuss and characterize major computing disciplines, including the emerging discipline DS. The model encourages systematic critical thinking and meaningful learning. Other contributions of the paper include the highlight of the relative lack of emphasis of all established computer disciplines on deep contemplation of why decisions are made. We argue that the fledging DS discipline is a good opportunity for the overall computing disciplines to focus on the why question, and argue that it should be a top focal area for DS.

This project can be extended and improved in many ways. The paper provides a simple model for understanding and characterizing computing disciplines. In order to be useful, it must provide values especially to laypersons such as general counselors and incoming students. We are currently designing experiments with general counselors in our college to use the model to aide incoming students. Surveys will then be conducted to study and assess the model's effectiveness. Another direction is to identify aptitude and psychological tests to determine students' interests and capabilities related to the four questions of the 3W1H model.

We are also looking into applying the investigation dimension not only for characterizing computing disciplines, but also microscopically on individual computing projects. Surveys and studies can be conducted on how beginners can understand and use the model to contemplate their careers in the computing disciplines. Best practices on how to use the model, including in conjunction with the two ACM dimensions, can be experimented and collected. We are also interested in studying other dimensions and perspectives, and investigate how different models may interact and complement each other.

Acknowledgements

We thank our students for raising questions related to the characterization of computing disciplines to us. We also thank the University of Houston-Clear Lake's Quality Enhancement Plan (QEP) Leadership Team for its support in our investigations on the critical thinking portion of this paper.

REFERENCES

Ausubel, D. 1963. *The psychology of meaningful verbal learning*. New York: Grune and Stratton.

ABET. 2017. "Accreditation Criteria," http://www.abet.org/accreditation/accreditation-criteria/, accessed 1/20/2017.

ACM. 2005. “Computing Curricula 2005 – The Overview Report,” http://www.acm.org/education/education/curric_vols/CC2005-March06Final.pdf.

ACM. 2008. “Information Technology 2008: Curriculum Guidelines for Undergraduate Degree Programs in Information Technology,” http://www.acm.org//education/curricula/IT2008%20Curriculum.pdf.

ACM. 2010. “IS2010, Curriculum Guidelines for Undergraduate Degree Programs in Information Systems,” http://www.acm.org/education/curricula/IS%202010%20ACM%20final.pdf.

ACM. 2013. “Computer Science Curricula 2013,” http://www.acm.org/education/CS2013-final-report.pdf.

ACM. 2014. “Software Engineering 2014 Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering,” http://www.acm.org/binaries/content/assets/education/se2014.pdf.

ACM. 2016. “Computer Engineering Curricula, 2016,” http://www.acm.org/binaries/content/assets/education/ce2016-final-report.pdf.

Anthony, E. 2003. “Computing education in academia: toward differentiating the disciplines,” in *Proceedings of the 4th conference on Information technology curriculum*, pp. 1-8.

Battig, E., & Shariq, M. 2011. “A Validation Study of Student Differentiation between Computing Disciplines,” *Information Systems Education Journal*, (9:5), 105.

Connolly, R., Lunt, B., Miller, J., & Powell, L. M. 2015. “Towards a Better Understanding of the Different Computing Disciplines,” in *Proceedings of the 16th Annual Conference on Information Technology Education*, pp. 55-56.

Copeland, R. 1995. “Rhetoric, hermeneutics, and translation in the Middle Ages: Academic traditions and vernacular texts (Vol. 11),” Cambridge, England: Cambridge University Press.

Courte, J., & Bishop-Clark, C. 2009. “Do students differentiate between computing disciplines?” *ACM SIGCSE Bulletin*, (41:1), pp. 29-33.

Davenport, T. & Patil, D. 2012. “Data Scientist: The Sexiest Job of the 21st Century,” *Harvard Business Review*.

Donoho, D. 2015. “50 years of Data Science,” in *Tukey Centennial Workshop*, Princeton NJ.

Gupta, B., Goul, M., & Dinter, B. 2015. “Business intelligence and big data in higher education: Status of a multi-year model curriculum development effort for business school undergraduates, MS graduates, and MBAs,” *Communications of the Association for Information Systems*, (36:23), pp. 449-476.

Jabar, M., Ahmadi, R., Shafazand, Y., Ghani, A., & Sidi, F. 2013. “An automated method for requirement determination and structuring based on 5W1H elements,” in *Fourth IEEE Control and System Graduate Research Colloquium (ICSGRC),* pp. 32-37.

Jeong-Dong, K., Son, J., & Doo-Kwon Baik. 2012. “CA5W1H onto: Ontological context-aware model based on 5W1H,” *International Journal of Distributed Sensor Networks*.

Kang, W., Holden, P., & Yu, Q. 2015. “Pillars of Analytics Applied in MS Degree in Information Sciences and Technologies,” in *Proceedings of the 16th Annual Conference on Information Technology Education*, pp. 83-88.

Ma, P., & Tao, D. 2016. “5W1H model for incentive mechanism in mobile crowd sensing,” in *2016 IEEE International Conference on Consumer Electronics-Taiwan (ICCE-TW)*, pp. 1-2).

Mahalik, P. 2017. “Using the Five W’s and One H Approach to Six Sigma,” *iSixSigma.com*, https://www.isixsigma.com/implementation/basics/using-five-ws-and-one-h-approach-six-sigma/.

Mills, R., Chudoba, K. & Olsen, D. 2016. IS “Programs Responding to Industry Demands for Data Scientists: A Comparison between 2011 – 2016,” Journal of Information Systems Education, (27:2), pp. 131-140.

O'Neil, C. 2016. *Weapons of math destruction: How big data increases inequality and threatens democracy*, Crown Publishing Group, NY.

Paul, R., and Elder, L. 2012. *Critical Thinking: Tools for Taking Charge of Your Learning and Your Life*, (3rd ed.) Prentice Hall.

Paul, R., and Elder, L. 2014. *Thinker's Guide to Scientific Thinking*, (3rd ed.) Foundation for Critical Thinking.

Priestley, J. 2017. "Picking a Data Science Program: The First Question to Ask," *Master's in Data Science Blog*, http://www.mastersindatascience.org/blog/picking-a-data-science-program/.

Royster, S. 2013. “Working with big data,” *Occupational Outlook Quarterly*, (57:3), pp. 1-10.

Shimazu, K., Arisawa, T., & Saito, I. 2006. “Interdisciplinary contents management using 5W1H interface for metadata,” in *Proceedings of the 2006 IEEE/WIC/ACM International Conference on Web Intelligence*, Hong Kong, pp. 909-912.

Tedre, M. & Sutinen, E. 2008. "Three Traditions of Computing: What Educators Should Know," *Computer Science Education*, (18:3), pp. 153-170

Uzoka, E., Connolly, R., Schroeder, M., Khemka, N., & Miller, J. 2013. "Computing is not a rock band: student understanding of the computing disciplines," in *Proceedings of the 14th annual ACM SIGITE conference on Information technology education*, Orlando, FL, pp. 115-120.

Vessey, I., Ramesh, V., & Glass, L. 2005. "A unified classification system for research in the computing disciplines. *Information and Software Technology*, (47:4), pp. 245-255.

De Veaux, D., Agarwal, M., Averett, M., Baumer, B., Bray, A., Bressoud, T., ... & Kim, A. 2017. "Curriculum Guidelines for Undergraduate Programs in Data Science," *Annu. Rev. Stat. Appl*, (4:2-1).

Wei, W. & Yue, K., Using Concept Maps to Teach and Assess Critical Thinking in IS Education, *Proceedings of the 22nd Americas Conference on Information Systems AMCIS*, San Diego, California, USA, August 2016.

Wikipedia. 2017. "5Ws," https://en.wikipedia.org/wiki/Five_Ws.