CHAPTER 2

Literature Review

Since this research attempts to identify a new approach for learning SGT based on an interdisciplinary background, the literature review consists of several areas. A bird's eye view of related works is shown in this section. Individual technical issues, e.g. user modeling and course sequencing, may not be well addressed in this chapter. These technical details are discussed in the subsequent chapters when the system design is described..

2.1 Theoretical background of learning with media

The term 'media' could be defined from different angles within wide extent. In [36], an appropriate definition of media is "Media are a diverse range of technologies and processes that humans use to explore, express or communicate ideas."

Examining characteristics of media could help us to realize media in depth. These characteristics are its *technology*, *symbol systems* and *processing capabilities* [49]. For instance, books, television and computers are technologies; Text, pictures, sound and 3D representations are symbol systems, and information is encoded in these modes. The feasibility of information retrieval on the Web is one kind of processing capabilities that television does not have [49].

The debate of the effects of learning with media has been discussing for a long period of time. The critical point is that *whether media influence learning or not*. It is important to notice that Clark claims that only instructional methods benefit learning but media do not [20], and Kozma's point is "media and method are inseparable" [49]. For developing effective Web-based learning, this argument actually reminds us to take instructional design as a main concern and to take advantage of the characteristics of computers and the Web on using these technologies. For Web hypermedia, it is almost impossible to replace some characteristics such as hyperlink by other technologies (ex. TV or books). Computers' capabilities enable novel instructional design that cannot be easily achieved by other technologies. When we consider media use in Web-based learning (WBL), it is better to integrate them into instructional methods tightly by taking cognitive effects into consideration.

The idea of using computers as cognitive media in education are proposed by researchers based on different theoretical foundation and observation. Some are from the aspect of educational media use [36] while others are based on multimedia studies [56]. The explanations of cognitive media by these works are not quite the same, but it is evident that most studies notice the debate we just mentioned. The consensus is clear that media should be used meaningfully and related to learning itself directly. Recker et al. define cognitive media as: "Cognitive media are based on a cognitive theory of the inferential and learning processes of human users, and encapsulate different methods or strategies for problem solving and learning. [56]"

Some researches on ITS and cognitive sciences consider computers as cognitive tools which implies that computers are tools to assist learners to accomplish cognitive tasks [48]. Different descriptions of computer's role in education—cognitive 'media' and cognitive 'tools'— are observed by different disciplines. As media, computer systems can store, deliver and represent contents. As tools, computers can help people to think, reason, and create ideas, which should be the elements of meaningful learning.

2.2 3D computer graphics in computer-based educational system

Several works in the literature focus on embedding 3D display into learning environments. Specifically, Virtual Reality (VR) receives considerable attentions by researchers. VR technology offers realistic, immersive and interactive environments to model and simulate the real world. Users are able to perform objects manipulation and scene navigation in this type of environments. Though the so-called 'VR' actually refers to a wide range of user interface technologies which may include hardware, software and their combination, most VR applications in education today prefer the pure software-oriented approach. That is, the most economical way of VR that needs no or few specific hardware devices such as VR-capable helmet and data glove, but could perform rather satisfactory effects by today's computers' computing power. The reasons are believed to be two-folded. On one hand, education is a business relating to a population of people, and thus it is necessary to design a system that uses *only* hardware devices available to most end-users. On the other hand, according to [70], devices like VR-capable helmet are not definitely effective. Besides the temporal insufficiency of computing power may make such devices not precise and robust enough for real-time interaction, it seems that not every task is suitable to employ these devices due to physically uncomfortable interference. Therefore, unless the domain to be learned is about specific procedural skills like flying the plane, the trend of VR in education has been shifted toward software-oriented approach. The specification of Virtual Reality Modeling Language (VRML) and Java 3D technology are examples of the software-oriented approach that have been frequently applied in educational settings. A detailed comparison and survey of these technologies in education has been presented in [52].

The VR paradigm—integrating navigation and interaction functionalities into flat screen display to form the complete 3D perception and cognition for users—has been used widely by computer games and Web 3D applications. [69], [71] and [79] are good examples of this approach in education. Among them, [69] is for space and life science education; [71] is for training operating skills of vessel machines; [79] is for safety training in chemistry laboratories.

The main objective of VR is pursuing the 'reality', that is, making the virtual world look more realistic. Besides VR, there exists another approach—*visualization* that employing computer graphics techniques to represent data, information and concepts in 3D media. In other words, the purpose of visualization is to model and visualize concepts what only exist in textual or mathematical symbol systems, which is very important for many fields of scientific researches. In computer science education, visualization and representation of algorithms is recognized to be effective if used appropriately [42]. Visualization is also beneficial for delivering scientific knowledge [25]. Instances that employed this approach cover almost all science education areas.

2.3 Intelligent tutoring system and adaptive educational hypermedia

The development of Intelligent Tutoring System (ITS) in the past 20 years accumulates substantial results based on AI and cognitive science researches. Most generic ITS architectures propose to build a good student model. The student model reflects systems' beliefs on learners' mastery level on particular concepts. Furthermore, it is the driving force that enables the system to perform individualized tutoring to learners [48]. By extending the generic architecture of ITS, various types of ITS have been developed based on different domains, pedagogical strategies and other affecting factors [51][71][79].

With the rapid development of Internet and World Wide Web, researchers attempted to deploy ITS on the Web. These systems retain most features of generic ITS architecture [51]. Among these approaches, Adaptive Hypermedia (AH) is a relatively new approach that accounts for *hypermedia* and *user modeling* fields together [12][14]. Web hypermedia generally comprises a large information space, so the need for adaptivity on the Web is evident specifically. For educational purpose, adaptive educational hypermedia (AEH) aims to adapt the content, which could be the presentation or the navigation guidance, with respect to individ-

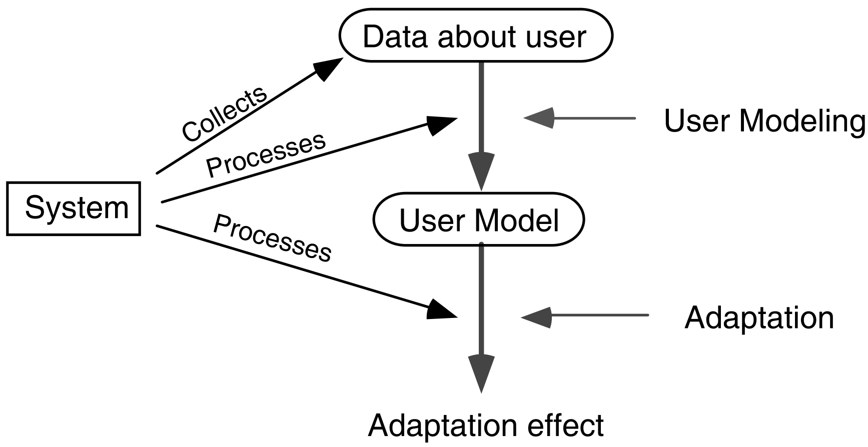

Figure 2. 1: Classic process of adaptation in adaptive systems [10]

ual's differences. In short, individual learners' cognition (changed usually) and traits (changed unusually) are what this kind of systems attempt to adapt to. Some studies have shown that adaptivity is potentially beneficial for Web-based learning [28].

2.3.1. Model- and procedure-based approaches for Web-based learning

Though AH systems are built upon the basis of hypermedia either on the Web or generic applications, but as in ITS, user (student) modeling plays an important role in the process of adaptation in AH systems. In Figure 2.1, Brusilovsky has illustrated a classic process of such a task [10]. The existence of student model in ITS and AH systems also makes they works in a quite different way compared to *procedure-based* educational systems, such as the mechanism of flow control used in classical computer-assisted instruction systems (CAI) and its modern successor—the specification of IMS simple sequencing (IMS SS) designed for the Leaning Objects (LO) paradigm [1][44]. The most significant difference between model- (i.e., ITS, AH) and procedure- (i.e., CAI, IMS SS) based approach is whether to model the user and the domain *explicitly* or not. We observe that model-based approach focuses on offering a system-level solution on adaptivity globally and systematically. While for procedure-based systems, such as IMS SS, sequencing rules determine the flow control which can also direct their learners to learn a topic step by step. The difference between the two might be hard to distinguish in some applications, such as Web-based learning, because the need of learning guidance seems could be addressed equally either by model-based mechanisms or by the use of sequencing rules. However, SS can only consider learners' performance locally. Since there is no student model could be employed to trace learners' performance at an abstract level (e.g., pieces of the learning domain, such as sub-topics, concepts etc.), it is likely that learners will be pushed to re-learn something he has learned in other courses even if that course is managed by the same Learning Management System (LMS). In other words, the procedure-based system is just like a teacher not knowing anything about the students but teach them all in the same way. We have suggested that under the LO paradigm, it would be beneficial to consider a model-based approach for better adaptivity. Meanwhile, reusability of LO is still tenable and ensured [75].

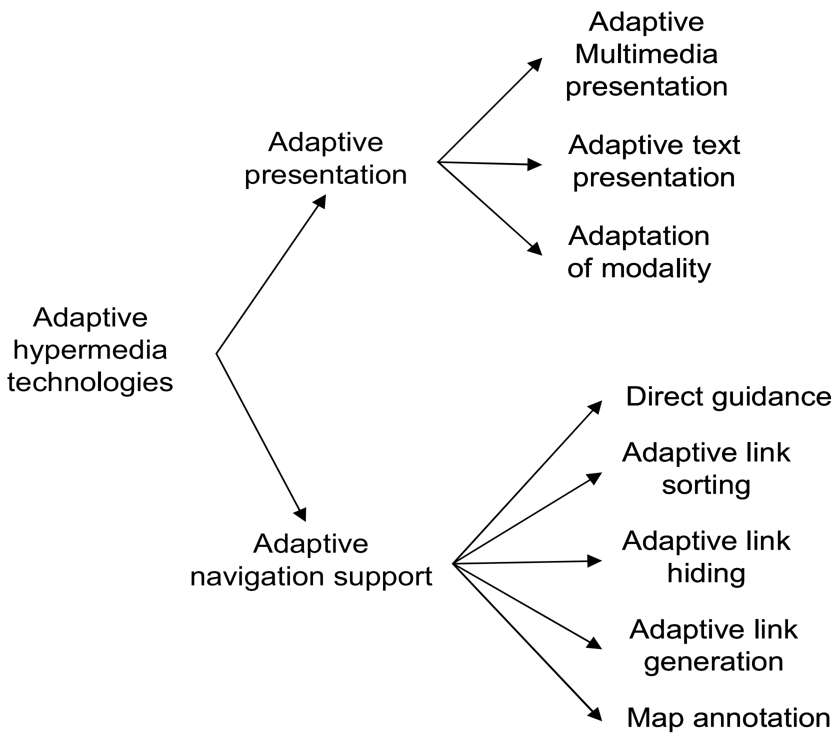

Figure 2. 2: Brusilovsky's taxonomy of AH technologies (partial) [14]

2.3.2. Methods and evaluation of methods in AH

As Brusilovsky mentioned in [14], AH is a field positioned on the crossroads of hypermedia and user modeling. Therefore, another task to be considered besides user modeling is about *what can be adapted in terms of the content or structure of hypermedia*. Brusilovsky has summarized the taxonomy of available AH methods today as shown partially in Figure 2.2. Two main categories of AH technologies been identified are content level adaptation or *adaptive presentation* and link level adaptation or *adaptive navigation support* [14]. It is worth noting that the methodology of empirical evaluation receives general agreement by practitioners of this field [17]. The purpose of all of these adaptive methods is clearly to support users' performance on a particular task, e.g., learning a topic. The common logic behind all adaptive methods would look like "*what if the system presents content (or links) to users in this way?*" These claims would need empirical evidence as support, such as an experiment comparing the difference between with- and without- adaptation effects. According to the state of art of AH, the investigation of system-level framework and adaptive methods have been becoming more and more mature. The missing-ring of AH is that more empirical evidence of the effectiveness on actual tasks is still needed. As Chin pointed out, “We must test the usefulness of user model adaptations through experiments before we can claim that they are useful. [17]”

However, since the methodology of AH evaluation stemming from experimental psychology and behavior sciences, the ambiguity and uncertainty of human behavior patterns makes it inherently challenging to conduct empirical evaluation on AH technologies. In related conferences on AH, workshops and tutorials targeted to discuss evaluation methods are often held specifically [2][31].

2.3.3. Difference between ITS and AEH

The consensus and differences between ITS and adaptive educational hypermedia (AEH) are briefly compared here. For ITS, intelligent behaviors of the system, e.g. tutoring discourse in natural language, diagnosis behavior are emphasized. Mapping to educational theory, typical ITS is closer to tutor-centered paradigm in general. ITS controls and decides what is best to learner firmly based on the system's student model. But under the development of novel media technology such as Web hypermedia, typical ITS approach may lack flexibility and usability since learners lose the chance to explore the information space e.g., browsing content freely as people used to do on the Web. Whereas for AEH is the main concern, offering learners adaptive presentation and navigation supports according to each learner's prior knowledge and preference. AEH is much closer to leaner-centered educational model, i.e. a model of constructivism. It also attempts to adapt the content to individual learner, but the adaptive design targets at sharing learners' cognitive load and/or reducing the hypermedia disorientation, not performing full intelligence to make all decisions. What we are discussing refers to the “*locus-of-control*” problem [21][74]. Which type of design would be proper depends largely on the learning domain and application context.

In this research, we propose to balance these two extremes via the separation of *concepts* and *learning materials*. At the concept level, the locus-of-control resides at tutor-side. So the program (i.e. the tutor) determines what concept to be presented. At the material level, the locus-of-control resides at user-side. Learners could freely browse learning materials. Nevertheless these materials are filtered and recommended by the tutor.

Beyond the differences between ITS and AEH, they are both designed to enhance the effect of learning in computer-based learning environment based on a very fundamental pedagogical principle in education — personalized learning will be better than the monolithic, one-size-fits-all means.

2.4 Spatial ability

Spatial ability is a psychometric construct that is recognized essential to activities related to spatial reasoning such as engineering activities and scientific thoughts [3][9]. In this study, we are interested in two problems: (1) *can we enhance spatial ability by using interactive 3D visualization?* (2) *how to make use of spatial ability as a basis to adapt the presentation?*

About the first problem, previous work indicated that spatial ability might be affected by spatial experiences [3]. Woolf et al. have proposed a tutoring system with 3D-based interaction and animation that is shown to be able to enhance spatial ability [77]. It is a general view that virtual reality and similar computer-based 3D environments can offer adequate spatial experiences for gaining spatial ability. But there still exists some debates. According to Clark's claim [20], only instructional method can influence learning, and media will not. Can we treat learners' gain on spatial ability as a type of learning? If so, does that spatial experience actually makes the enhancement in these previous works? Or is it possible that the enhancement is due to the methods embedded? To address these issues, we have conducted a preliminary evaluation in order to assess the effects of using interactive 3D media to enhance spatial ability. A class of undergraduate level students attended the evaluation. We will describe the experiment in Chapter 4.

About the second problem, two assumptions are given in this study. *First*, learners with different spatial ability should receive contents with different types of media representations as assistance. *Second*, the higher a learner's spatial ability is, the less degree of visualization she/he will need. For example, if 2D-based (i.e., texts and diagrams) and 3D-based illustrations (i.e., interactive 3D media) are both available for describing a concept, we could scaffold learners with low spatial ability by adopting 3D visualization. For learners with enough spatial reasoning skills, letting the learner practice to form and manipulate the mental image with 2D-based representation is reasonable. This is because learners with high spatial ability could construct and think in spatial relations in her/his mind more smoothly in general. With the design of differentiated degrees of visualization, the theory of cognitive scaffolding is also considered for adapting the presentation to learners' spatial skills.

2.5 Learning styles

By considering adaptive educational systems, the first coming issue is naturally to ask "*what information is different between individual learners?*" That is, it is essential to identify types of information associated with learners, and then the task of adaptivity could be done accordingly. Moreover, such information should be a meaningful discrimination in terms of learning. The most significant information been used in most adaptive systems is learners' *knowledge*. By considering what the user has known or unknown, the system generates appropriate adaptation effect in terms of her/his knowledge status of the learning domain. Under the scenario of Web-based learning, the corresponding adaptation effects usually appear in the form of adaptive navigation support e.g., for links that is not fitting to learners' knowledge status, they are hidden or grayed by the system as facilitation.

Besides learners' knowledge or performance on the topics to be learned (i.e., the learning domain), another type of learners' difference measure is considered potentially beneficial for adaptivity, *different ways that people learn*. This is so-called *learning styles*. A rather clear explanation on learning styles [26] is as "… (learning styles are) strategies, or regular mental behaviors, habitually applied to learning, particularly deliberate educational learning, and built on her/his underlying potentials." Many endeavors are to identify features of learning styles that can classify learners into distinguishable extremes of that feature For example, *visual learners* who intend to learn with pictorial representations and *verbal learners* who prefer to read words. *Visual* and *verbal* are proposed as two end points laid upon the same continuum of learning style. Some other features like FD (field dependent)/FI (field independent) learners, sequential/global learners etc., have been frequently imported into educational settings as the basis of instructional design [29].

Some study suggested that for learners with different learning styles, it is the best to apply teaching styles that match the learning styles Researchers have formulated models of instructional methods addressing this concern [29]. Two points are worth noting here. *First*, however, *whether learning styles matter for learning or not* seems inconclusive. Draper indicated that very few empirical studies can reveal statistical interaction effects between learning and teaching styles. That is, the necessity of considering matching them is doubted [26]. It is suspected that the influence of learning styles on learning could be rather small comparing to other factors appearing in classrooms. But it is also noted that the scenario might be different for computer-based learning [26]. Some studies have detected the interaction between learning styles and tutoring strategies embedded in computer-based learning systems [60][66][1]. *Second*, some researchers suggested that for learners with different learning styles, the principle that teachers (systems) should take is not to determine and choose each student's preferred instructional method [30]. Instead of changing (i.e., adapting) the teaching styles, it is better to require learners to learn *how to learn*. What teachers (systems) have to do is to *equally* address the needs of different learning styles during the teaching session, and train learners learn to cope with non-preferred teaching methods meta-cognitively [26][30]. In our point of view, AH could cope with this philosophy better than ITS similar to the situation of locus-of-control mentioned previously.

Relating learning styles to ITS and AH is natural. No matter the influence of learning styles is large or not, many human tutors have observed their students' "styles" informally. And then they have chosen the way they think best about tutoring that student. This concern is different to the concern of prior knowledge possessed by students, though sometimes the two concerns seem to overlap. For example, some learners are observed to learn more "slowly" than the population. This is a concern of styles, probably due to the mismatching of styles or the absence of particular reasoning skills (e.g., spatial ability), but not just a concern of knowledge. Evidently, human tutors would easily detect this fact, tune their progress to be more flexible, and repeat tutoring the topic in various approaches respectively. Transforming the concern of from human tutoring to computerized tutoring is challenging. Less attention has been paid on this issue in the past, and the integration is just about to begin [62]. By today's computing power and multimedia capability, it is optimistic that AH could adapt to learning styles better than classroom-based lecturing. It is still unclear that which type of instructional strategies should be taken to tackle learning styles (i.e., matching of styles vs. addressing all styles equally). We recognized that this should be an important factor that should

[1] The interaction effect is not claimed by that paper, but could be inferred via the experimental result clearly.

be accounted for by designing AH in terms of learning styles. We have conducted an experiment to take a look at this point, and will be described in Chapter 5.