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Using hypermedia for learning complex concepts in chemistry: A qualitative study on the relationship between prior knowledge, beliefs, and motivation

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Abstract This paper reports the results of a qualitative study on the process of learning complex concepts in chemistry by four students as they worked with FLiPS (Flexible Learning in the Periodic System), a cognitive flexibility multi-media hypertext for learning about the periodic system of elements. A wide range of probes (think-alouds; navigation logs; observational notes, interviews; pre- and post-tests; epistemic beliefs survey; and background questionnaire) produced a rich data set for analysis. This data was analyzed to construct rich narrative case- and cross-case narratives of the participants' process of working and learning in this complex hypertext environment. This multi-level analysis offers insight both into the fine-grained process of use as well as the larger issues of the pedagogical significance of FLiPS. Our analysis reveals a complex relationship between epistemic beliefs, student motivation, prior knowledge, and process of learning from hypertext. We offer implications for future research, design and the application of pedagogical hypertexts.

Keywords Multimedia/hypermedia systems · Pedagogical issues · Applications in subject areas · Interactive learning environments · Teaching/learning strategies

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Introduction

Computer based hypertexts—texts written specifically for taking advantage of the computer's capability to organize information in a decentralized, non-linear and multiply-linked manner—have been seen as a cognitive tool of great promise for the purposeful learning of complex material (Jonnasen, 1991; Spiro and Jehng, 1990). The arguments made for using hypertexts in learning include, greater learner control; improved access to multimedia learning materials; and a variety of new modalities of interaction for use with learning material (Shapiro and Niederhauser, 2004). However, the findings of the research on learning from hypertext are often inconsistent and contradictory. Some of this research has been criticized for not being guided by educational theories based on cognitive principles of learning (Dillon and Gabbard, 1998; Mishra *et al.*, 1996). It has been argued that research and design of educational hypertexts has often been driven more by enthusiasm for the computer, rather than reliable knowledge of the human user (Dillon, 1996; Dillon and Gabbard, 1998).

There are a variety of issues that complicate research into learning with hypertexts (Sharpio and Neiderhauser, 2004). Hypertexts, by their very nature, resist step-by-step navigation, and give the user a variety of ways to navigate and criss-cross the information available (Kluwe, 1995). Differences in usage patterns of the hypertext could also reflect on the manner in which the information is perceived and understood. Moreover, the interaction of these variables with individual differences is not well understood. The focus of future research, it has been argued, should be "identifying the precise combination of design attributes, task domains, and learner characteristics" (Dillon and Gabbard, 1998, p. 322).

There are three key factors that need to be considered when thinking of educational hypertexts in specific (and educational technology in general): the content to be covered; the pedagogy or learning theory that is appropriate for teaching the content; and finally, the affordances provided by technology that allow for the integration of content and pedagogy (Bhatnagar and Mishra, 2003; Mishra, 1998; Mishra and Koehler, 2006). Cognitive Flexibility Theory (CFT) has been proposed as being an appropriate learning theory for knowledge acquisition in complex domains. The field of chemistry (and in particular the chemistry of the periodic system of elements) can be fruitfully seen as being a complex domain that requires a context sensitive understanding of the interplay of multiple concepts through multiple representational formats (Kozma *et al.*, 2000; Spiro *et al.*, 1991). CFT has been used to design a range of hypermedia systems. In this study, we have used CFT as the basis for designing FLiPS (Flexible Learning in the Periodic System), a web-based hypertext that allows learner to interact with the complex nature of the periodic system. It is a multi-level, multi-stage hypertext that emphasizes learning by "criss-crossing" the multiple representations of the periodic system in a flexible and open-ended manner.

In this paper we begin with a description of the domain, i.e. the periodic system of elements. We ground our argument through an analysis of alternative representations of the periodic system that have been proposed by scientists as well as through a description of FLiPS, a CFT based hypertext system. We then report the results of a qualitative study on the process of learning complex concepts in chemistry by four students (three men and one woman) as they worked with FLiPS. We offer detailed case studies and a cross-case analysis based on a wide range of data—from learning outcomes emphasized by theory to the actual patterns of student interaction with FLiPS. We believe that this multi-level analysis offers insight both into the fine-grained process of use as well as the larger issues of the pedagogical significance of FLiPS.

Introducing the periodic system

Chemistry has received far less attention from educational researchers especially when compared to other domains such as physics, biology or mathematics (Anderson, 1986; Carter and Brickhouse, 1989; Kozma and Johnston, 1990; Krajcik, 1991). In general prior research indicates that an expert chemist's understanding of chemical concepts is embedded in a conceptual framework that they have developed over time through the active integration and structuring of concepts about the nature of matter and chemical change. In contrast to the experts, studies reveal that even after a year of chemistry instruction, students lack conceptual understanding of fundamental chemical concepts and their inter-relationships (Anderson, 1986; Ben-Zvi *et al.*, 1986, 1987; Eichinger and Lee, 1988; Hesse and Anderson, 1988; Krajcik, 1991; Osborne and Cosgrove, 1983; Yarroch, 1985). Krajcik (1991) highlights this point, "Students use the 'correct' words and apply formulas to obtain correct answers but lack understanding of the underlying chemical and physical concepts" (p. 119).

Some indication of the potential source of the problems students faced in learning chemistry can be found in a study that probed differences between students and experts in their perception of chemistry (Carter and Brickhouse, 1989). They found that the most significant difference between experts and novices related to their beliefs about the nature of chemistry. Experts were more likely than students to say that chemistry is simply difficult and saw student difficulties arising from the fact that chemistry is "abstract and requires a special way of thinking" (Carter and Brickhouse, 1989, p. 225). Students, on the other hand, were algorithm-dependent i.e. seeing chemistry as being based on rules rather than on abstract conceptualizations.

One of the most important constructs in chemistry is the periodic system. It is a crucial "conceptual tool" that organizes the entire field of chemistry and helps chemists and students develop an integrated framework for further learning and exploration (Atkins, 1995; Cooper, 1968; Cox, 1989; Emsley, 1989; Hoffman, 1995; Idhe, 1964; Mazurs, 1974; Rich, 1963). The periodic system helps us see and appreciate some very significant patterns across the elements—patterns that helped us conceptualize the periodic system in the first place. However, seeing these patterns or similarities across groups and within periodic families does not mean that everything is homogeneous within that group or family. The theme of "the same yet not the same" repeats itself throughout the periodic system—and also at different levels of analysis (Hoffman, 1995). The "special way of thinking" argued by the experts in the Carter and Brickhouse study, entails a view of the elements and their relationships with each other that is multi-dimensional, context-sensitive and flexible. Constructing any instructional framework for teaching the chemistry of the periodic system must take this "same yet not the same" behavior into consideration. This is an area where expert and novice understandings come into serious conflict (as suggested by Carter and Brickhouse (1989)).

However, students often do not understand the value of the periodic system (Campbell, 1989; Woodgate, 1995). Students see the construction of the periodic table as being driven by simple rules, with multiple exceptions to these rules (Carter and Brickhouse, 1989; Rich, 1963). However, experts, see the periodic system as being a rich, complex and ill-structured domain—dependent on the interplay of a multitude of concepts and *allowing for multiple representational formats*. One significant indication of how experts view the periodic system is the fact that they keep creating new versions of the table. The periodic system of elements (the word "system" is used to distinguish it from a specific representation) contains within it an infinitely large number of possible representations. As Rich (1963) says in his book *Periodic Correlations*:

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub						

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Fig. 1 The standard form of the Periodic Table. This is the most popular form of the table. It does a good job of combining the electronic configuration table and a chemical table. However, in this manner it does not do full justice to either

> One of the fascinations of inorganic chemistry is the existence of a wide variety of relationships among the elements and their properties—relationships that show an encouraging degree of order, but a tantalizing variability and novelty. These qualities make the "family of elements" an apt metaphor: while members of a family have much in common, each member also has his [sic] own individual personality. The quality of relatedness among elements makes periodic tables possible. *But the diversity of their interrelationships bars any one table from a monopoly on the advantages* (p. xx, italics added).

This is the reason why, though a single representation—a modification of the original Mendeleev version—dominates most textbooks, chemists have not stopped trying to create new tables (Mazurs, 1974; Rich, 1963; van Spronsen, 1969). Over the years, hundreds of versions of the periodic table have been proposed, each attempting to map out the complex relationships among the elements or groups of elements. It has been cast into three-dimensional forms (spirals, screws, cones and spheres) as well as many two-dimensional types (Mazurs, 1974; van Spronsen, 1969). Mazurs (1974) documents around 450 different tables and a search of the literature reveals that there are even more. Figure 1, 2, 3 and 4 offer examples of different representations of the table, with brief descriptions of their unique features. (More extensive descriptions of these tables can be found in Mazurs (1974), Mishra (1998) and Rich (1963)). It is important to note that: *Any given visual representation of the periodic table of elements is but one of an indefinitely large number of tables that might be produced. The issue then becomes which representations are useful for what tasks.*

We have argued that a better understanding of the complex relationships inherent in the periodic system of elements will allow students to develop a deeper understanding of chemistry (Mishra and Nguyen-Jahiel, 1998; Mishra, 1998). The periodic system of elements is the bridge between the atomic world and the world around us. A good grasp of the fundamentals of the periodic system would prevent students from "seeing the atomic world as a extrapolation of the macroscopic one" (Anderson, 1986, p. 553).

However, just knowing that these multiple representations exist is not enough. The educational goal for teaching such a complex domain then becomes helping students develop into flexible thinkers and problem solvers who see both the patterns and the variability of use inherent in the periodic system. Some help in this regard comes from Cognitive Flexibility Theory-CFT (Feltovich *et al.*, 1993; Mishra *et al.*, 1996). CFT argues that in ill-structured

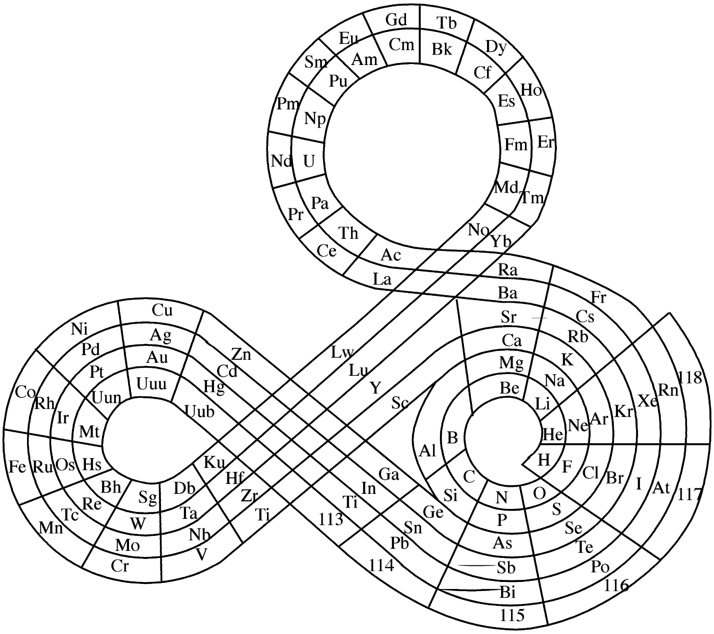


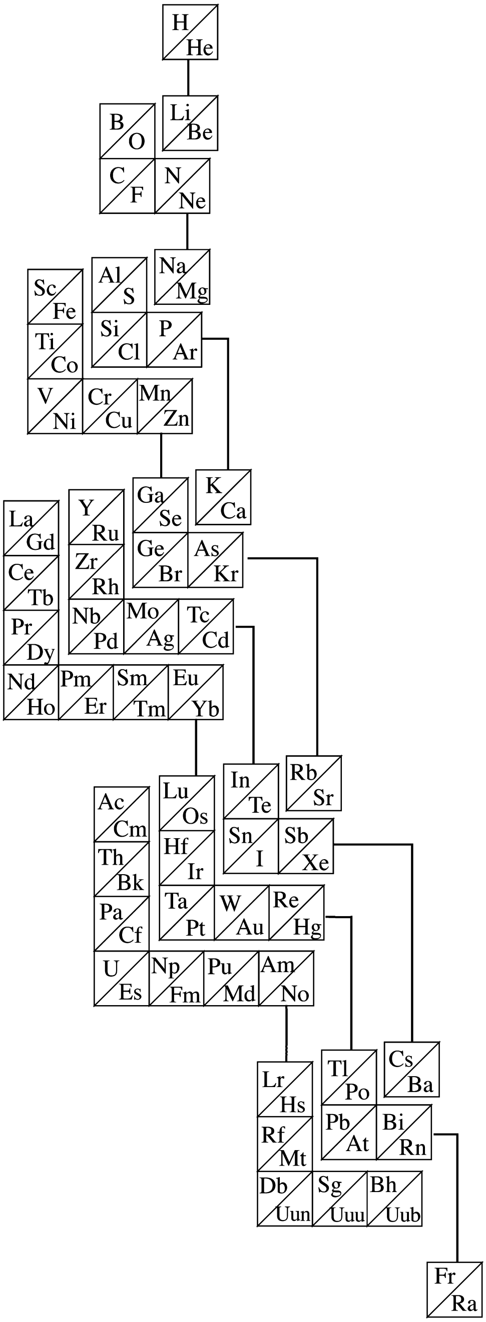
Fig. 2 Janet's Spiral Table. Developed in 1928, Janet's Spiral is a good continuous table though it may be difficult to read in some versions. However, it gets its significance from the fact that it can be dissected in various ways. It can be seen as the top view of a three-dimensional helical form. It can also be "cut" to generate the chemical and standard tables as well as "unwound" to generate the valence chain or graphical tables

domains, flexible cognitive representations (as opposed to rigid knowledge structures) enhance the transfer of knowledge to contexts different from those that had been involved originally in the teaching of the material. CFT lends itself prescriptively to the design of complex, multidimensional, and nonlinear environments (Spiro and Jehng, 1990)—specifically computer based hypertexts—for enabling students to learn complex domains and also to apply this knowledge in new contexts (Jacobson and Spiro, 1995). CFT emphasizes the construction of flexible, context sensitive understanding of complex domains through using multiple representations, metaphors and perspectives (Mishra *et al.*, 1996; Spiro and Jehng, 1990). Our description of the periodic system (with its rich and complex relationships at multiple levels and multiple representational formats) combined with the inadequate nature of students understanding of these issues, make a CFT-hypertext particularly appropriate for instruction in this domain.

Introducing FLiPS: Flexible learning in the periodic system

FLiPS (Flexible Learning in the Periodic System) is a prototype multi-media, multiple representational hypertext for learning complex (and often hard to learn) concepts in chemistry. It is a CFT hypertext in that it emphasizes the construction of flexible, context sensitive understanding of the periodic system of elements through using multiple representations and perspectives (Mishra *et al.*, 1996; Spiro and Jehng, 1990).

Fig. 3 Treptow's Table. Elements are arranged in squares with square denoting a period. This is a very unique way of looking at electronic configuration by pairing elements (within a square) that have electrons with opposing spins. Not necessarily a good table for understanding the chemical properties of elements.



FLiPS is not just a database of elements—many of these exist, both in book and in electronic form. However, traditional databases do not really exploit or demonstrate the periodic characteristics of the elements. FLiPS goes beyond that by allowing the learner to see connections between chemical concepts at three levels: (1) among specific chemical elements; (2) groups of elements; and (3) different periodic representations. The first level

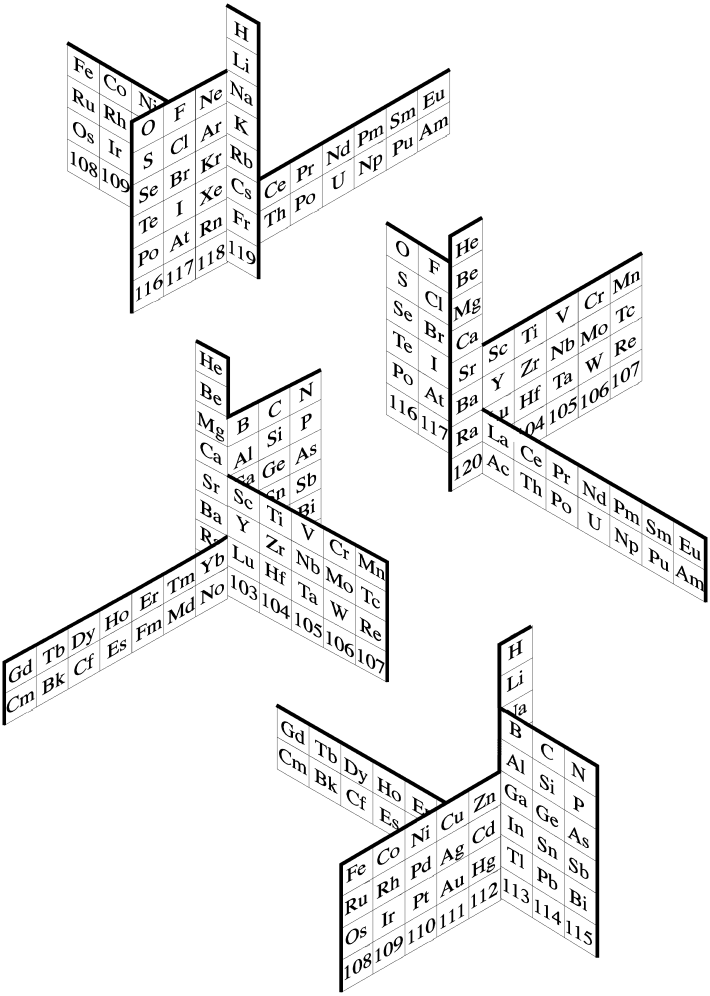


Fig. 4 Gigure's three-dimensional model. This table provides a unique perspective to the manner in which sub-shells and shells get filled with electrons. Being a 3-dimensional model it is difficult to represent and use in 2 dimensions

emphasizes the unique nature and properties of each element—as well as providing hints to similarities and differences across them. The second level reveals patterns and exceptions in the chemical and physical properties of groups of elements. The third level of FLiPS links between various representations of the periodic system, allowing students to compare these different representations (tables, spirals, linear charts and so on) along a variety of dimensions. This level allows the learner to see the entire periodic system through different lenses or perspectives. Different representations have different strengths and weaknesses and emphasize different relationships.

These three levels of FLiPS allow the student to see the periodic system as being a fluid and dynamic set of relationships that can be seen and understood in multiple ways. FLiPS also permits contextual linking between a variety of representational systems—such as the

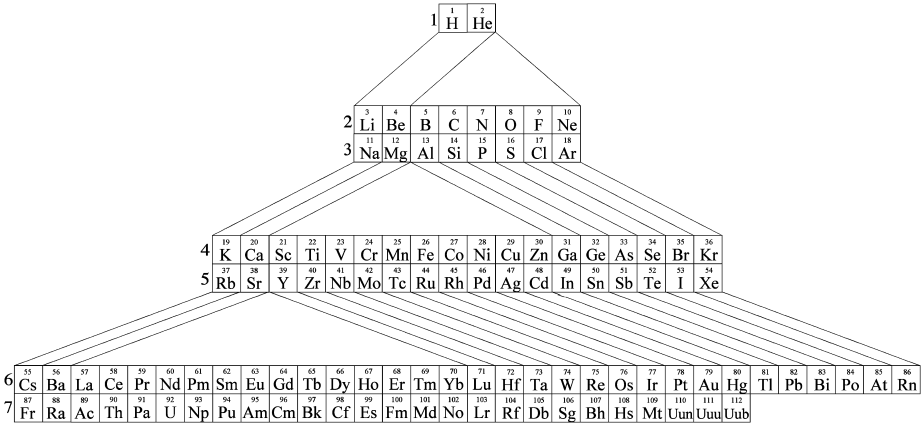


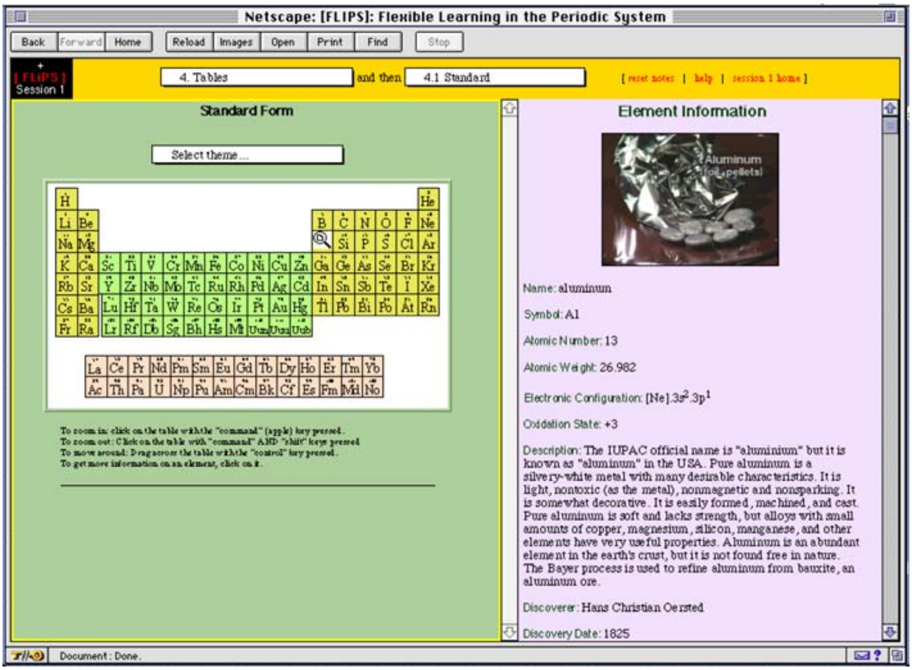
Fig. 5 Pyramid table. The pyramid table is a symmetric table depicting the "repetitive" nature of the Periodic Law. The s, p, d & f blocks are not distinctly designated and since it clumps rows together it requires connecting lines to highlight links between similar elements or groups of elements

different representations of the periodic system, photographic images of the elements, graphs and charts of the properties of the elements, illustrations and animations. Seeing a variety of visual representations of the periodic system (and the chemical elements that comprise these tables) and being allowed to compare and contrast their strengths and weaknesses enables students to see relationships that previously seemed intangible and vague when discussed using just a single representation. The software effectively allows students to criss-cross the complex landscape of the periodic system, comparing and contrasting different representations and revisiting them in different contexts, allowing them to cultivate multifaceted and flexible knowledge representations that can be used in many kinds of situations and contexts.

FLiPS is open-ended in that it allows one to investigate relationships that may not have been easy to accomplish using other media. FLiPS offers students a variety of contexts within which to think of periodicity and emphasizes the inexhaustibility of understanding that lies in the Periodic System. In a fundamental way it embeds, or prefigures, (Mishra *et al.*, 1996) within itself knowledge of chemistry and the kinds of relationships that are viable. FLiPS offers students a compliant guiding framework for exploring the periodic system of elements (Mishra *et al.*, 1996) allowing them to get an insider's view of expert knowledge in the domain. In that sense the design of FLiPS is an example of how the triad of content, pedagogy and technology need to be integrated for the design of pedagogical systems (Bhatnagar and Mishra, 2003; Mishra, 1998; Mishra and Koehler, 2006). (For a more detailed description of FLiPS see Mishra, 1998; Mishra *et al.*, 1999).

Individual characteristics of hypertext use

There has been a great deal of research attention paid to individual characteristics and their relationship to learning from hypertext (Dillon and Gabbard, 1998; Hartley and Bendixen, 2001; Shapiro and Neiderhauser, 2004). Reviewing the literature on hypertext learning Tergan (1997) concluded that "individual learning prerequisites . . . may override structural parameters of hypertext/hypermedia documents in affecting performance" (p. 263). Similarly, Dillon



4. Tables

4.1 Standard

Select theme ...

To zoom in: click on the table with the "command" (apple) key pressed.
To zoom out: Click on the table with "command" AND "shift" keys pressed.
To move around: Drag across the table with the "control" key pressed.
To get more information on an element, click on it.

Name: aluminum

Symbol: Al

Atomic Number: 13

Atomic Weight: 26.982

Electronic Configuration: $[Ne].3s^2.3p^1$

Oxidation State: +3

Description: The IUPAC official name is "aluminium" but it is known as "aluminum" in the USA. Pure aluminum is a silvery-white metal with many desirable characteristics. It is light, nontoxic (as the metal), nonmagnetic and nonsparking. It is somewhat decorative. It is easily formed, machined, and cast. Pure aluminum is soft and lacks strength, but alloys with small amounts of copper, magnesium, silicon, manganese, and other elements have very useful properties. Aluminum is an abundant element in the earth's crust, but it is not found free in nature. The Bayer process is used to refine aluminum from bauxite, an aluminum ore.

Discoverer: Hans Christian Oersted

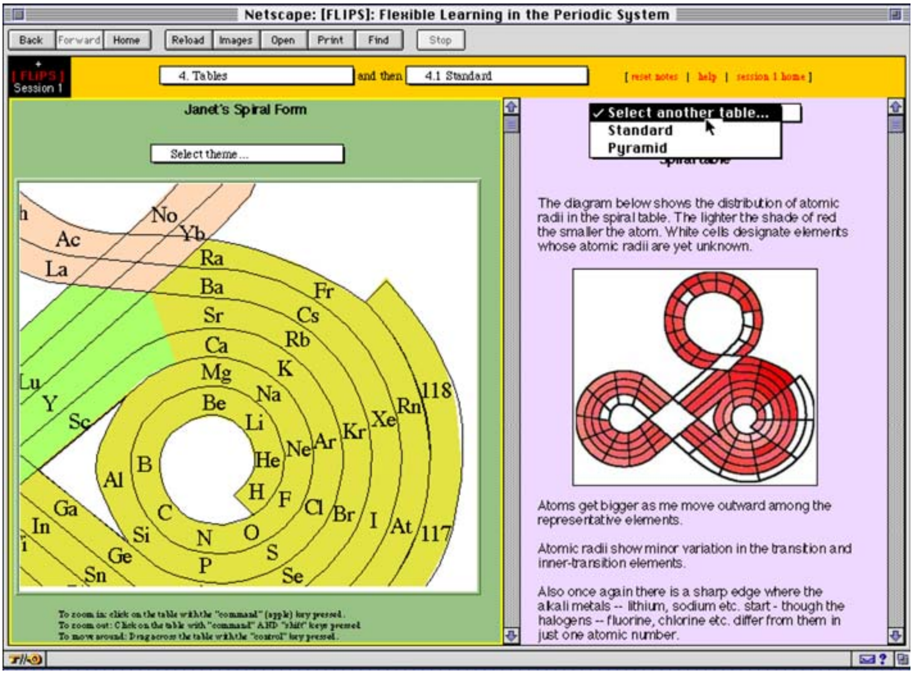
Discovery Date: 1825

Fig. 6 Screen from session 1 (criss-crossing phase) showing the standard table in the main frame with data on aluminum displayed in the notes/commentary frame

and Gabbard (1998) suggest that these individual characteristics may offer "the beginnings of an explanation for the generally conflicting results in literature" (p. 344). A part of the problem has been that the findings of the learner characteristics research are often contradictory and inconclusive. A range of user characteristics have been studied including, learning styles (Korthauer, 1994; Liu and Reed, 1994; Melara, 1996); prior knowledge (Chen and Ford, 2000; Gall and Hannafin, 1994; Tergan, 1997); field dependence and independence (Jonassen and Wang, 1993; Lin and Davidson-Shivers, 1996); reading patterns (Balcytiene, 1990; Lawless and Brown, 1997; Lawless and Kulikowich, 1996); motivation (Chen and Ford, 2000); and epistemic beliefs (Jacobson and Spiro, 1995; Jacobson *et al.*, 1996). Two of the relatively stable factors that have been found to influence learning from hypertext are: learners' prior knowledge and epistemic beliefs.

Prior Knowledge: Research shows that low prior knowledge readers tend to benefit from more structured program-controlled hypertexts, whereas high-prior knowledge readers tend to make good use of more learner-controlled systems (Balajthy, 1990; Gall and Hannafin, 1994). The argument is that learners with high-prior knowledge can invoke schemas that help them integrate newer information. Those with low-prior knowledge do not have these pre-existing schemas that they can call upon when needed (Gall and Hannafin, 1994). In addition, the theoretical framework we are using in this paper (CFT) is essentially a theory of advanced learning in ill-structured domains. This demands that learners have certain basic knowledge of the domain prior to working with FLiPS.

Epistemic Beliefs: The Carter and Brickhouse (1989) study indicates that beliefs about the domain are the single most important factor distinguishing between expert and novice conceptualization of chemistry. This finding is consistent with current research on people's



The diagram below shows the distribution of atomic radii in the spiral table. The lighter the shade of red the smaller the atom. White cells designate elements whose atomic radii are yet unknown.

Atoms get bigger as me move outward among the representative elements.

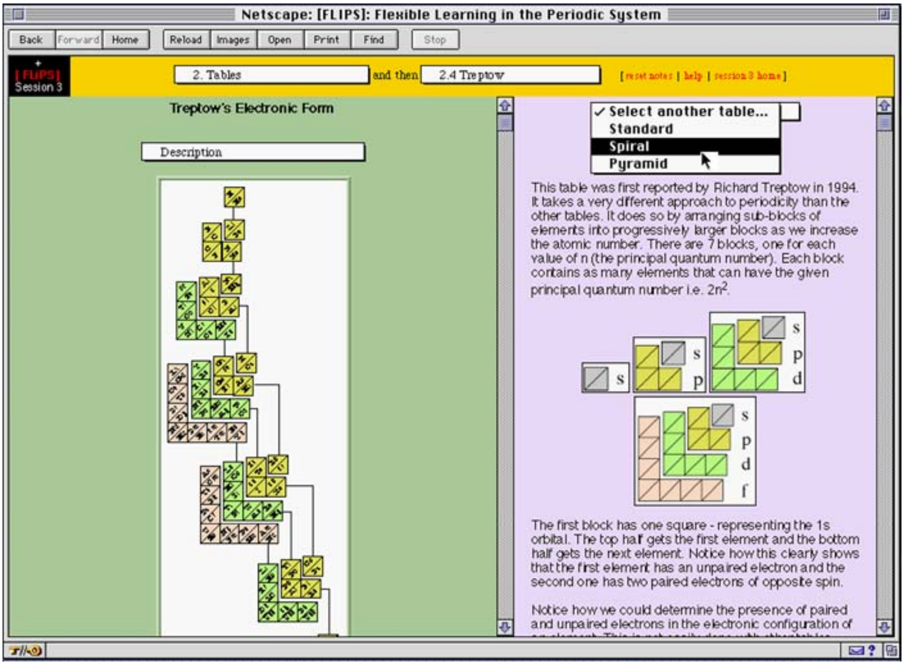
Atomic radii show minor variation in the transition and inner-transition elements.

Also once again there is a sharp edge where the alkali metals -- lithium, sodium etc. start - though the halogens -- fluorine, chlorine etc. differ from them in just one atomic number.

To zoom in: click on the table with the "command" (apple) key pressed.
To zoom out: Click on the table with "command" AND "shift" keys pressed.
To move around: Drag across the table with the "control" key pressed.

Fig. 7 Screen shot from session 3 (criss-crossing phase) showing a magnified Spiral table in the main frame with its a secondary table giving the distribution of atomic radii in the notes/commentary frame. The pull down menu shows the process of criss-crossing in progress

epistemological (or epistemic) beliefs (Feltovich *et al.*, 1989; Jehng *et al.*, 1993; Perry, 1968; Schoenfeld, 1983; Schommer, 1993, 1994; Schommer *et al.*, 1997). Epistemic beliefs may be regarded as general assumptions held by the learner about the nature of learning and knowledge (Schommer, 1993). Beliefs about the nature of the world and the nature of knowledge can impact the cognitive resources that a learner may provide a particular domain of study (Schoenfeld, 1983, 1985). Epistemic beliefs can also contribute to a range of learning difficulties: from poor reading comprehension caused by problems in integrating prior knowledge to new knowledge (Schommer, 1993), problem-solving failure in mathematics (Schoenfeld, 1983, 1985), and the development of fundamental misconceptions in bio-medicine (Feltovich *et al.*, 1989). Epistemic beliefs also impact how students comprehend texts (Schommer, 1990; Schommer *et al.*, 1992); how they interpret information (Schommer, 1990); how they monitor their comprehension (Ryan, 1984). Students with simple beliefs (such as the belief that knowledge is made up of isolated facts) have difficulty in comprehending information in complex domains such as statistics and bio-medicine (Schommer *et al.*, 1992; Spiro *et al.*, 1988). In general, students (consistent with research on chemistry learning) misunderstand complex concepts due to oversimplification and compartmentalization. Students with simple beliefs find it difficult to understand the complex interconnection of ideas in ill-structured disciplines. Simple beliefs about the nature of the world, or of learning may be appropriate for introductory learning or for learning in simple domains. However such beliefs may hinder learning at a more advanced level or in domains that are complex and ill-structured (Mishra *et al.*, 1996).



This table was first reported by Richard Treptow in 1994. It takes a very different approach to periodicity than the other tables. It does so by arranging sub-blocks of elements into progressively larger blocks as we increase the atomic number. There are 7 blocks, one for each value of n (the principal quantum number). Each block contains as many elements that can have the given principal quantum number i.e. $2n^2$.

The first block has one square - representing the 1s orbital. The top half gets the first element and the bottom half gets the next element. Notice how this clearly shows that the first element has an unpaired electron and the second one has two paired electrons of opposite spin.

Notice how we could determine the presence of paired and unpaired electrons in the electronic configuration of

Fig. 8 Screen from session 3 (criss-crossing phase) showing Treptow's table in the main frame with its description in the notes commentary frame. The pull down menu shows the process of criss-crossing in progress

There is evidence that a student's epistemic beliefs can impact the manner in which they learn from hypertexts (Hannafin and Land, 1997; Jacobson *et al.*, 1996; Land and Green, 2000). There is some indication that people with more complex beliefs prefer such non-linear media and learn more from it (Jacobson and Spiro, 1995).

Research design

It has been claimed that CFT hypertexts through their use of multiple modes of representation and multiple levels of interconnectedness should help learners go beyond merely memorizing facts to the development of a deeper understanding of important but complex knowledge about the chemistry of elements. Moreover, learners would be able to transfer this knowledge to new contexts. There are some preliminary experimental results of research into CFT hypertexts (though not in the domain of chemistry) that support this claim (Jacobson and Spiro, 1995; Jacobson *et al.*, 1996). Also important to understand are questions such as: How is the learning from the software driven by the participants' prior knowledge and beliefs about the nature of chemistry and/or the nature of learning and knowledge? Do learners with more complex or sophisticated beliefs about the nature of learning and knowledge feel more comfortable with the hypertext? What strategies do the learners use in order to make sense of this new medium? What patterns of navigation do readers follow in working with the hypertext and how are these strategies related to their ability to solve (or not solve) the problems they are given?

We attempt to answer these questions by developing rich narrative case- and cross-case analyses of individuals, their backgrounds, beliefs, and process of working and learning with FLiPS. The case study approach is prompted by a belief that, "single case studies provide rich data bases for the cognitive activity and problem solving behavior of individuals. They provide a much more fine grained picture of the individual problem solving process than do average data... Finally, single case studies can reveal important individual differences." (Kluwe, 1995, p. 271).

As suggested by Miles and Huberman (1994) analysis of multiple cases is well suited to understanding more varied phenomena such as where certain events are likely to occur or not occur, identification of negative cases, and the formation of general categories of how certain conditions may be related. By analyzing four cases, we were able to take the analysis beyond a simple single case study, evaluation study, or comparison study and deepen understanding and explanation of the activity. Analyzing four cases allowed us to focus on understanding the uniqueness within each case and similarities and differences across cases while avoiding simple "either-or" dichotomous conclusions of "better than" and "worse than." We see this research as an important first step prior to developing general principles of hypertext usage.

Participants

The participants were four students (three undergraduates and one graduate) at a large mid-western university. One of the undergraduate participants was a woman. All four were paid for their participation. The primary criteria for selecting these four participants was that all four of them had at least two university level courses in chemistry. Further details about each of the participants can be found in the case profiles given below.

Method

Each participant met with the researcher for three sessions of approximately 1.5 hours each. On the first session they signed a consent form and completed a background questionnaire. They then completed a test of their epistemological beliefs and a pre-test on chemistry. After brief training with FLiPS and the think-aloud process they began working with FLiPS. The first session ended with a short interview. The second session began with a brief interview followed by their working with FLiPS. The third session began with their working on the software and ended with an interview and a post-test on chemistry. Finally, the participants were given some debriefing information about the study they had participated in.

Each session on the computer was in two parts—a reading session, followed by a criss-crossing session (consistent with previous research in hypertext use, see Jacobson *et al.*, 1996). Both parts also contained a series of on-line problem solving exercises. Further details are given below.

Materials

Software

For the purposes of the study FLiPS was divided into three independent modules—one for each session. Each module, in turn, has two sections: a reading section and a criss-crossing section. The participants completed the reading section before going on to the criss-crossing section. The reading section was set up in an electronic book format and the participants traversed the information in sequence from the first topic to the last. The reading session was not strictly linear since there were hypertextual links within the text to images, graphs etc. The reading section also contained on-line problem solving questions to test the participant's understanding of the topic at hand. The criss-crossing section offered a series of periodic representations indexed with the conceptual themes. The participants answered a series of on-line questions by criss-crossing the different representations (and conceptual themes). Apart from these on-line problem solving questions they are also asked to think of these different representations in terms of how they related to each other.

Though structurally the three modules were similar they differed from each other in terms of, the number of representations, the number of concepts and the depth of information provided. The first session introduced three representations (the standard—Figure 1, the spiral—Figure 2 and the pyramid—Figure 3) and restricted itself to explaining certain basic concepts of periodicity and their relationship to the three representations. The second module added further information on electronic configuration as well as one more representation (Treptow's table—Figure 4). The final session had a very brief reading section (essentially a review of previous concepts) and a more complete criss-crossing section with two on-line problem solving transfer questions.

Probe materials

A variety of probe materials were used for this study. The general form of the probes can be seen as an "hour-glass" i.e. starting with general and open-ended interviews; narrowing to more focused problem solving tasks and exercises; and finally building back to a general conceptual level (Feltovich *et al.*, 1989). These probe materials are discussed in greater detail below.

Background questionnaire

The questionnaire was primarily in three parts: (a) general information about the participants' gender, age, educational qualifications, their academic and non-academic interests; (b) their prior experience with computers, their comfort level and familiarity with various software in general and hypertext in particular; (c) their prior background in science and chemistry

Cognitive flexibility inventory

The cognitive flexibility inventory is a questionnaire intended to determine the epistemic beliefs of the respondents (Spiro *et al.*, 1989/1996). There are 50 items in the CFI, made up of 25 pairs of items that are polar opposites of each other with regard to aspects of simplicity-complexity. These items can be broadly categorized into two groups: ontological beliefs, i.e. beliefs about the nature of the world; and epistemological beliefs i.e. beliefs about the nature of knowledge and learning. For each item, the respondents could provide a rating from 1–6, with the lower end of the scale indicating "totally disagree" and the upper end indicating "agree completely." Each individual had three scores reported: (a) a composite score for all 50 items; (b) a score for the ontological belief items (i.e. their beliefs about the nature of the world); and (c) a score for the epistemological items (i.e. their beliefs about the nature of knowledge and learning. The final scores are reported on a scale of 1 through 6 with 1 being at the simplistic end, and 6 being at the complexity end of the continuum.

Pre-test and post-test

The pre-test was a paper and pencil test to assess the knowledge of the periodic system of elements. Questions in this task included both multiple choice items and short answer questions. The multiple choice questions tested for factual knowledge while the short answer questions tested their conceptual understanding. The post-test included all the questions in the pre-test with some additional transfer questions. The participants could get a maximum of 50 points on the pre-test and 70 on the post-test (20 points for the additional transfer questions).

Think-aloud protocols

In an attempt to keep track of the thinking, navigation patterns and problem solving strategies used by the participants, they were asked to report their thoughts while they worked on FLiPS (Ericsson and Simon, 1984, 1993). Participants comments and reactions were audio-taped and later transcribed.

Observational notes

The primary author also took observational notes during all the sessions. These informal, ethnographic notes were used as secondary data to complement the analysis and interpretation of the data.

Navigation logs

FLiPS maintained a continuous log of the choices made by the participants, and when the choices were made. These logs were then used to develop navigational diagrams that represented the choices made by the participants.

On-line problem solving

An important part of FLiPS is the integration of problem solving tasks within the software. These problem-solving tasks played a dual role: they acted both as tools for evaluation of a student's understanding; as well as a technique to foster active learning by challenging the users to think through what they have learned. There were three types of problem solving tasks: factual, near-transfer and far-transfer. Factual questions often involved finding answers that had been directly mentioned in FLiPS, such as the electronic configuration of an element. A near-transfer question forced the learners to apply what they have learned to similar (but not the same) situations such as determining the electronic configuration of an element that had not previously been covered in FLiPS. A far-transfer question required the student to not just have understood the material but also to be able to apply it to a new context. For instance, the learner could be asked to explain the relationship between electronegativity and periodicity based on their understanding of the periodicity of atomic radius.

Interviews

The participants were interviewed at the beginning and end of each session (except the beginning of the third session). The questions asked during the interviews fall into three broad categories: (a) questions on chemistry; (b) questions on their beliefs on learning; and (c) questions on their experience with FLiPS.

The analysis

These probes (think alouds; navigation logs; observational notes, interviews; pre- and post-tests; Cognitive Flexibility Inventory; and background questionnaire) produced a rich data set for analysis. All sources of data were reviewed and analyzed together, however the think-alouds were the primary focus of analysis with the other sources of data (observational notes, navigation logs, beliefs survey, background information, pre-and post test scores) serving a supportive role (i.e., corroboration or refutation of the think-aloud data). Information from the background questionnaire, the CFI, the pre- and post-tests as well as the interviews made it possible to understand the participants' prior knowledge and beliefs about both chemistry and the process of learning. Combining the information from the navigation logs and the think-aloud protocols allowed tracking the manner in which the participant used FLiPS while reading and problem solving.

The transcribed think-alouds were read multiple times to get a more holistic conception of the content, to find instances that related to the research questions, to uncover unanticipated side issues and to identify themes and sub themes. This technique facilitated decisions about which data chunks to pull out, which patterns best summarized a number of chunks and which stories were emerging (Miles and Huberman, 1994). As suggested by Erickson (1986), Fetterman (1991), and Miles and Huberman (1994), our purpose was to look for key linkages among the data that supported or refuted the major themes and sub-themes as well as patterns or generalizations within and between cases. A conscious attempt was also made to link the cases and the supportive data, even while looking for negative instances to disconfirm the links or that suggested new connections that needed to be made. The final goal in creating the case profiles was to "open up" the data for analysis and interpretation (Seidman, 1998) and to transform the data into a story, which is one way that people make sense of themselves and their social world (Mishler, 1986).

The analysis of the protocols was both bottom up (i.e. from their actual actions and comments) and top down (i.e. guided by what we are looking for, such as conceptual coherence, changes in epistemic beliefs and so on). This bi-directional approach to the data allowed the investigation of important issues while maintaining the primacy of the actual data.

The next section takes each individual in turn and offers a detailed narrative of each participant and provides a profile of their working with FLiPS. Each individual profile contains, (a) a general portrait developed from their background questionnaire, the CFI and their answers to the interview questions; as well as (b) a detailed narrative about their working with FLiPS.[1]

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[1] The quotes taken from the interviews and think-alouds have been "cleaned up" to remove certain characteristics of oral speech that a participant would not use in writing. For example, repetitious "uhms," "ahs," "you knows," pauses, and other such idiosyncrasies that do not do the participant justice in a written version of what he or she has said were deleted (Seidman, 1998). This liberty was justified since the transcripts were not the basis of fine-grained discourse or linguistic analysis. In each case where such changes were made, we took care to maintain the original intent of the speaker and in situations where we believed edits would change the intent, we did not make any changes.

Donald

Background

Donald was a sophomore in chemistry who had completed five semesters of chemistry and had received 3 As and 2 Bs. Donald received 3.02 on the Cognitive Flexibility Index which puts him marginally towards the simplistic end of the simple-complex belief continuum. His beliefs about the world and his beliefs about the nature of knowledge and learning were quite closely matched (3.1 for the ontological items and 2.9 for the epistemological ones, Table 2). This is consistent with his interview responses. For instance he said that "Getting the right answer" was most important aspect of learning. When asked what motivated him most, he said. "if I am in a class I wanna be the top student in the class and that motivates me. I guess competition motivates me."

Despite his good grades in chemistry, Donald's knowledge of chemistry was limited and fragmented (scoring just 12.5 out of a possible 50 points on the pre-test), lacking an understanding of the underlying concepts. Most of his responses to the short answer questions were simplistic and incomplete. Most revealing was his answer to the question, why some scientists believe that silicon could be the basis of life on some other planets (just as carbon is on earth). He wrote: "Silicon has the *same* chemical properties as carbon" [italics added]. Not only does this answer offer no explanation for why this should be the case it mistakenly states that the two elements were identical, when in fact they were similar (but not same)—a fundamental distinction, that chemists often emphasize.

Working with FLiPS

Donald did not seem to have any significant problems with the think-aloud procedure. He occasionally found the navigation procedure in FLiPS to be "kind of confusing." Despite all this, he felt that the experience was "good" and that he had "really learned something while I was doing it."

During the reading sessions, Donald followed a fixed pattern of navigation. He would choose a certain concept (usually the first in the menu) and go from table to table till he had exhausted all the tables for that given concept. He would then select a new concept and repeat the procedure for all the tables available.

Consistent with what he had said in his interview, Donald spent much of his time, during online problem solving, trying to get the right answer. However, he was hampered by his tendency to jump to conclusions without necessarily going through all the information available to him, or just accepting information at face value and not attempting to integrate what he was reading or doing with his prior knowledge. For instance, after reading the description of ionization energy he said, "basically it is just the reverse of electronegativity," not taking care to notice that the pattern of distribution for both were very similar.

He often used a simple "surface" criteria of proximity when attempting to understand how chemical properties were mapped in different representations. Thus a table would be deemed successful if it placed similar elements together. The fact that elements could be arranged in different ways depending on other more conceptual or abstract principles often eluded him. This is revealed in the post interview where in describing the Periodic system he said, "It is just a way of arranging atoms or elements so it is easy to tell properties about them by just looking at where they are in a table."

This emphasis on viewing the “superficial” characteristics of the different tables prevented him from looking deeper at the concepts underlying these different representations. While looking at the manner in which solids, liquids and gases were represented on the Treptow’s table during session 2, he said, “Oh that makes it weak. The gases aren’t together, there are some metals in there, and they are all in the s block but there are not really together.” The fact that the organizational principle behind Treptow’s table is very different from that of the other tables, and that this table requires a new conceptual framework, was not considered. Neither was he aware of the fact that he was conflating the state (solid, liquid or gas) of an element with metallic or non-metallic characteristics. This incident of using concepts and chemistry terms loosely is not an isolated one but rather one that happened quite often (a similar example from his post-test is described below).

Often his answers to the on-line questions would be a mere re-stating of the information available directly in front of him. For instance, when asked a question about the relationship between ionization energies and metallic and non-metallic properties he just basically described the image in front of him, which in this case was a secondary standard table showing the location of the metals, non-metals and semi-metals. He said, “Looks like all metallic elements have the same properties, they are separated from the non-metals, and these [points with cursor] are kind of like in between. I don’t see any trends in ionization energy and metallic properties.” And this was said without even looking at the secondary tables for ionization energy where these patterns were more clearly observable.

Donald’s style of working and thinking is most revealed during the criss-crossing sessions. In an answer to the far transfer question about electron affinity he focused on just one table—the standard representation, making an argument by drawing an analogy between electron affinity and electronegativity. When asked to describe the causes behind the pattern of distribution of electron affinity he answered not by offering an explanation in terms of electron configuration but rather by describing his process of getting at the answer. He said: “What would I look for? Basically something similar that I know of already like I was looking at electron affinity, and I’m like OK that’s gaining electrons and I know that’s like electronegativity and I know that has a set pattern to it. So I just kind of compared it to something I already knew.”

Donald also seemed to base his answers on a “theory” he developed often based on partial data. For instance, when asked whether the reactivity of the alkali elements would increase or decrease as we increased atomic number he based his answer on a “simple theory” that lower electronegativity implied lower reactivity. However, he was not sensitive to the fact that electronegativity plays out differently (in fact, in opposite directions) with metals and non-metals. However, even when faced with information that contradicted his “theory” Donald would not take that extra step of questioning his ideas.

Donald’s navigation patterns indicated his emphasis on a single representation. For instance, his navigation patterns while answering the second criss-crossing question indicates how he always went back to the standard table. Though the navigational patterns seem to suggest that he looked at each table and theme while formulating his answer, his think-alouds reveal a different story (See Figure 9). He almost always used the standard table for formulating his answer and his “visits” to the other representations were perfunctory at best (both in terms of what he said and the amount of time he spent on these pages). This focus on one table is clearly visible in the map of his navigational choices (see Figure 9, specifically link 3, 7, 11, 15 and 20).

His emphasis on getting the right answer sometimes frustrated him while working on the program. Some of the on-line questions, which were aimed at testing their understanding,

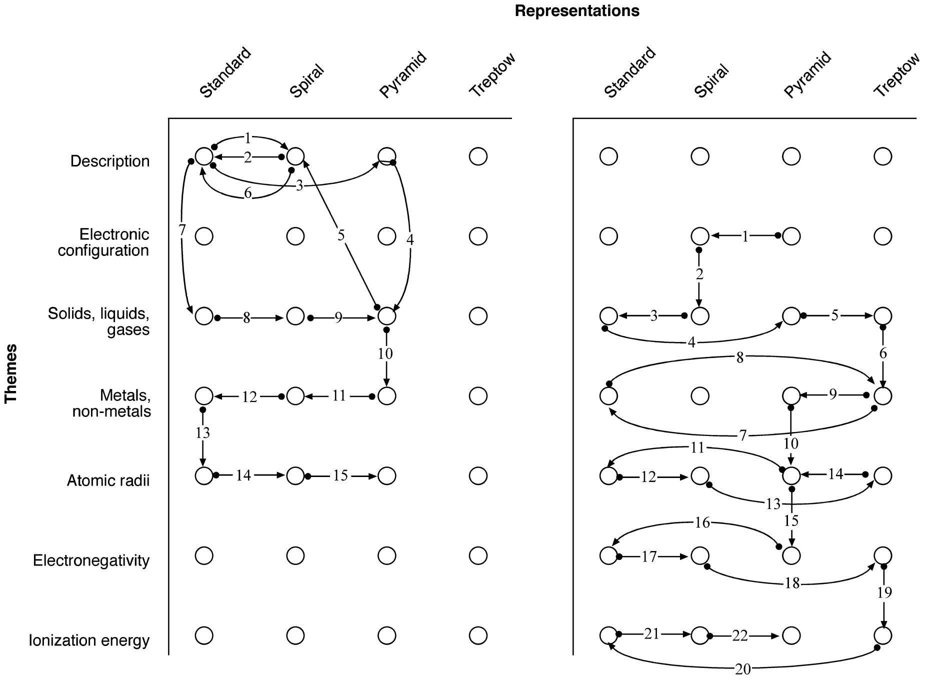

Fig. 9 Sample navigation patterns for Donald. From Session 1 and Session 2

did not provide the answers. Donald was the only one who was bothered by this fact. During his final interview when asked if there was anything that he would like to comment on he said that something that had bothered him was that, "there's a lot of questions that you are trying to come up with the answers and then you don't find the answers—so it asks you like tell me the electronic configurations and then you don't find the answer 'coz you want to make sure you got it right."

Summing up

Donald learned some chemistry through working with FLiPS. His post-test scores showed a marked improvement. They went from 12.5 to 32. Table 1 shows his scores by question type—factual, near transfer, far transfer as well as for the complete test. It is clear that he showed greatest improvement in his answers to the factual questions as opposed to the near and far transfer questions. This is consistent with his epistemic beliefs which pay a greater emphasis on factual knowledge (over more abstract forms).

That said, his answers to the short-answer questions became more complex and he became more aware of distinguishing between "same" and "similar" characteristics. For instance, in an answer to the question about sulfur and oxygen he wrote, "Sulfur and oxygen have similar chemical properties and have similar electronic configurations." (That is, he first wrote the word "same," crossed it out and replaced it with "similar.") When asked about what the single most important thing that he had learned he said, "just basically, . . . how there is more than one possibility for learning this and how they can all help you learn the same concepts, basically like concepts were like electronegativity and electron configuration about how using

Table 1 Pre-and post-test scorse for all four participantes

Question-type	Participant	Pre-test	Post-test	Total on final
Factual[a]	Donald	5	15	17
	Martin	4	17.5	19.5
	Susan	4	14	14
	Terry	7	21	23
Near Transfer[b]	Donald	6.5	11	11
	Martin	9	10	10
	Susan	3	4	4
	Terry	9	10	10
Far Transfer[c]	Donald	1	6	13
	Martin	2	6	18
	Susan	1	4	8
	Terry	6	7	19
Total[d]	Donald	12.5	32	41
	Martin	15	33.5	47.5
	Susan	8	22	26
	Terry	22	38	52

Note:

[a] Maximum score possible for the factual items on pre- and post-test = 26; on the complete test = 28.

[b] Maximum score possible for the near transfer items on pre- and post-test as well as the complete test = 14.

[c] Maximum score possible for the far transfer items on pre- and post-test = 10; on the complete test = 28.

[d] Maximum score possible for the entire test on pre- and post-test = 50; on the complete test = 70.

different tables can be better than one." Also when asked if his thinking about chemistry had changed in any way, he said, "Well it just made me more open to different ideas. I had always thought that there's only one table I never knew there were other tables."

However, in many ways, Donald, did not exploit FLiPS to the fullest. Part of the reason could be that he was just more comfortable with the standard form of the table. However, it seems that there were other factors (both internal and external) that would have not made FLiPS the best learning tool for him. The fact that he worked on FLiPS in a research setting, rather than in a regular classroom, where he could compare himself against others could have played a role in his manner of interaction. Competition was important to him and the formal research setting did not offer that to him. His belief that the world was essentially a simple place may also have affected his interaction with FLiPS and possibly explains why he would just stick to the first explanation (or theory) that occurred to him, or to just one representation, rather than explore and try to understand the concept from multiple perspectives. This may also be part of the reason why he occasionally felt that the navigation procedure was confusing.

Martin

Background

Martin was a Caucasian, 23-year-old, first year masters certification student in Curriculum and Instruction, with a bachelor's degree in Kinesiology. He had five chemistry related courses and obtained one C, two B's and two A's in the five courses. Martin scored 4.36 on the CFI, which puts him in the complexity end of the simplicity-complexity continuum (Table 2). He seemed to have a more complex set of beliefs about the nature of learning and knowledge (4.63) as opposed to his beliefs about the nature of the world (3.5). Martin saw the process of learning from the perspective of a classroom teacher—something he hoped to become.

Table 2 Cognitive flexibility inventory scores for all four participants

Participants	Ontological beliefs	Epistemological beliefs	CFI Score
Donald	3.1	2.9	3.02
Martin	3.5	4.63	4.36
Susan	3.17	4.05	3.84
Terry	3.5	4.34	4.14

Notes: Scores range between 1 and 6. A score of 1 indicates simple beliefs while 6 indicates complex beliefs.

He described his philosophy of learning as emphasizing "hands on learning, with things that they can see; they can do." However, he was aware that "that's not always possible." To the question why learning was important to him he said, "I guess my whole personal stuff is curiosity, I mean I see things and it just makes me curious more and more. I just want to know. There are certain things that I'd like to definitely learn more about than others but I love just learning about different things. Things that I just have no idea about." Though he did not under-estimate the value of extrinsic factors such as grades he felt that his primary motivation was intrinsic, "I want to see what's gonna happen here, you know just from my own curiosity."

Despite his background in chemistry Martin was very aware that his chemistry knowledge was "rusty." This was reflected in his pre-test scores which were 15 on a possible 50. His lack of knowledge can also be inferred from his description of the periodic table he gave in his first interview. He said, "I know it's basically, it's an arrangement of the elements which is based on their atomic weights." A common misconception that has been identified in the literature (Anderson, 1986; Woodgate, 1995).

Working with FLiPS

Martin was not entirely comfortable with the think-aloud procedure but had no problems with the user interface and felt that using FLiPS was "a good experience." During the reading sessions Martin went through the tables and the commentaries in sequence, finishing all the commentaries for a table before moving on to the next representation. He also read very carefully—rarely skipping information.

Though familiar with the standard periodic table he was not fully aware of the idea of periodicity. This can be seen by his prediction that atomic radii would increase as the atomic number increased. He said, "atomic radii to atomic number should have a direct relationship, as one increases the other should increase as well, in a straight line." Seeing the actual pattern of peaks and troughs, surprised him, "hmm, lot of variations. Some higher atomic numbers have lower radius." At one level, his surprise is an indication of his "rusty" understanding of periodicity but at another it indicates that he is prepared to understand what it means. Martin was also quite reflective about his learning such as his comment about the spiral table after the first session. He said, "I don't didn't know the spiral [form] had been developed in the 1928 and I had never come across it in anything I had ever seen. It seems like it sacrifices a lot of this general information and that may just be because I am not really familiar with it. I don't, I'm not really sure on how to interpret it. From what I can tell it does a fairly good job of organizing in terms of similarities." He seemed much more comfortable with the spiral table by the last session. He said, "[The] Spiral table as I am becoming more familiar with it it's getting easier to use 'cos I'm seeing patterns and I'm seeing how the elements are grouped and, and the same way there I am using it more and it's starting make more sense. I'm starting to see the same patterns that I see in the standard table."

He became sensitive to the problems with the standard table when we used it to determine the electronic configurations for some elements. The separation of the inner-transition elements from the main table confused him. He had to use a mnemonic introduced in a previous section to get the right answer. He described his process (and offered insight into what had gone wrong) as follows, "start with xenon the noble gas and then come back, and then we have the two, six *s* two that goes with the *s* over here, and four *f* fourteen and that goes with these inner transition elements which have been taken out. That's why it was kind of hard to see, I think, that's because those are out of there [the table]." This made him appreciate the pyramid table because, as he said, "actually makes it a little easier to see than the standard table, because, I mean, the inner-transition is not taken out."

Martin's extremely structured navigational choices indicate his thorough approach towards answering each problem-solving question. In his criss-crossing phase Martin maintained his step-by-step navigation technique, methodically going through each theme for a given representation before moving on to the other one, something most clearly seen in his navigation logs (See Figure 10).

His answers to most on-line questions were well reasoned and thought out. For instance, to a question on the relationship between metallic properties and electronegativity he tied in information from electronic configuration, differences in atomic radii to develop a strong coherent answer. During the criss-crossing sessions he usually started with the standard table, since as he said, "That's the one I am familiar with." However he looked at all the tables and

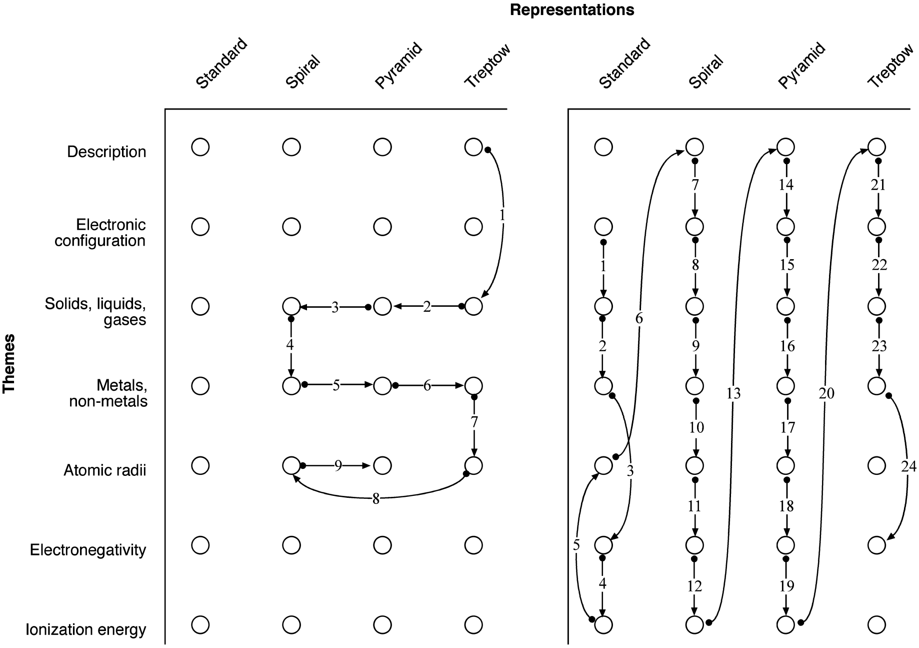

Fig. 10 Sample navigation patterns for Martin. From Session 1 and Session 2

compared them to each other to develop his answer. When comparing tables he would look at the concepts that underlay each of these tables in order to develop his answer. Initially, he felt that the standard form was the best table to see patterns in electron affinity. However, looking over all the tables carefully he felt that the spiral and the pyramid form could do a good job as well. He felt that this choice at some level boiled down to "personal choice" though he did admit that the spiral table "could be easier since this is continuous [and] you know how to interpret it."

Summing up

Martin's post-test scores (33.5 on 50) and the relative complexity of his thought processes as he worked on the online problems, attest to the fact that he learned quite a bit while using FLiPS. Table 1 shows his scores by question type—factual, near transfer, far transfer as well as for the complete test. It is clear that he showed improvement in his answers to the factual and the transfer questions.

In addition, his answers to questions integrated a variety of concepts and representations to develop rich and nuanced answers. And though he still tended to prefer the standard table (due to, as he said, its familiarity) he was also more aware of its limitations. Martin also became sensitive to the fact that the patterns in the periodic system of elements often have exceptions. A good example of this was his answer to the question why copper and zinc are sometimes regarded as being part of the transition elements even though some tables do not include them in that group. Though he did not provide the exact electronic configuration for these elements he was the only one among the four participants who noticed that these elements had exceptional electronic configurations that resemble those of the transition elements.

Despite the fact that Martin preferred open-ended hands on activities for learning science he performed quite well with FLiPS. He exploited its criss-crossing capabilities to develop his answers. He described his experience with the non-linearity of criss-crossing as follows: "It makes you think, which is good. It helps you understand chemistry more too, it comes down to a matter of you understanding what is going on." Though he did not feel that his thinking of chemistry had changed in any way he did agree that it was "good to see these different representations." He felt that he had "more tools now to use, so that in terms of thinking about [or] in terms of solving things I have definitely its changed a lot. I know I have more out there for me now."

It appears that Martin's relatively complex beliefs about the nature of knowledge allowed him to exploit the criss-crossing functionality of FLiPS to develop nuanced and sensitive understandings of the topic at hand. His internal motivation (that he described as a curiosity to learn) appeared to make him willing to interact with the information, consider alternative approaches, and develop his answer. Though somewhat hampered by his "rusty" knowledge of chemistry, Martin was able to utilize the multiple opportunities to traverse the periodic system to develop his understanding.

What is interesting is that this complexity of beliefs (that helped him learn about the periodic system) is not reflected in his navigation patterns. Martin's navigation patterns (see Figure 10) are extremely methodical and sequenced. He would choose one periodic representation, follow all the nodes keeping the representation constant and then repeat the sequence again for a different representation. So his complex epistemic beliefs are reflected more in what he did with the knowledge than with the nature of navigating through the hypermedia.

Susan

Background

Susan was a 20-year old, Caucasian, junior in agricultural science and agriculture education with some background in chemistry (one course in high school and two at the university), she had received just a C+ in her university courses. Susan received 3.84 on the Cognitive Flexibility Index, which puts her very marginally into the complex half of the continuum (Table 2). She seemed to have a slightly more complex set of beliefs about the nature of learning and knowledge (4.05) in contrast to her beliefs about the nature of the world (3.17).

Learning for Susan depended on what she was interested in and whether the topic made sense to her personally. She said she was motivated by "finding answers, to questions that I have pertaining to things in *my life*" [italics added]. Learning to her was for a particular purpose. For instance, when asked why learning was important to her, she said, "I am from a farm. I want to understand why the corn grows, why we fertilize, why if you don't do this, this happens, why the yields are lower."

Though being interested in the topic to be learned was important to her, in certain significant ways Susan's philosophy of learning was a passive one. It was based on being *taught* by somebody else. She said, "I believe my learning philosophy would be I like to learn from someone who wants to teach me. From someone who is honest with me and expected of me learning what they teach." Susan had not reflected much about how she herself learned. When asked about what her approach would be if she had to learn something on her own, she said, "My philosophy of learning would be just try and figure it out. I don't know, just like, I don't know." When asked to describe her best learning experience she talked of a trip she had taken to Europe with a large group of students. Interestingly (and consistent with her passive approach towards learning) she said that what made the learning "really good" was that "we were sort of *forced into* [it], I mean, not forced, we wanted to go but *we were forced into the situation where the leaders of the group wanted us to ask questions. So we had to ask questions and pay attention and all that*" [italics added].

Susan had a weak understanding of chemical concepts and facts. She received 8 (out of a possible 50 points) in her pre-test. She often gave answers that, at best, could be called non-answers. For instance her answer to the question about why atomic radii increased as we went down a period in the standard table she wrote, "Because the elements are larger." Similarly, when asked to describe the periodic table, during the initial interview, she said, "I know what it looks like, I know that it lists the different elements." She did not seem very aware of her lack of knowledge though and often felt that she knew and understood the standard form.

Working with FLiPS

Susan was quite comfortable with the think aloud procedure. While working with FLiPS, Susan can be described as being "click-happy," i.e. she would follow links just because they were there and thus, often, got lost or was unsure of why she was at a certain screen. Her comment, "I'm not exactly sure why I am looking at this," exemplifies the nature of her interaction with FLiPS.

Her lack of background knowledge often affected her reading and navigation. She would focus on tiny details but the larger picture would escape her. She tended to skim passages or ignore whole sections of information. Many times while working with FLiPS she would get stuck on certain basic foundational concepts. Her weak knowledge of chemistry, her inclination to skim over information, coupled with her tendency to click on links without much thought, often led her astray. She often tried to solve problems by attempting to infer patterns in the examples provided. However, the patterns she inferred were often not ones that could be supported by the data and explanation given. For instance, here is Susan trying to figure out how many electrons go into a shell, "*d* there is five, and *f* there is seven, five and seven [inaudible] three and five, is fifteen and four times seven is... twenty-eight, so the answer is fifteen plus twenty-eight. Is that right? [she checks the answer provided.] Oh! I took this to mean, this two right here, two times like three to get six. Then I took three times the five, instead of two times the five, and four times the seven instead of two times the seven, OK. Now I know." This process of misreading, misinterpreting and going back once the mistake became clear is something that happened quite often.

Her feeling that she knew the standard table often got in the way of her grasping the other tables. During the first session she compared the different representations to each other by going back and forth between them. However, she stopped doing that in the second and third sessions and focused her attention primarily on the standard form.

Similar to her pretest responses, some of her answers to the on-line questions were just statements of fact. She would not expand and integrate her answers with what she had read. An example of such a response is when she was asked to explain the manner in which ionization energies and metallic properties are related. She said, "As we go down a group we increase the size of the atom adding additional shells. As we stay in the same shell while the number of protons increases, this explains why the metallic elements have ionization energies." She provided no explanation as to what the relationship between the shells and ionization energies and metallic properties is. Moreover, it seems from her answer that only metals have ionization energies and the other elements do not.

Susan's fragmented knowledge of chemistry coupled with her tendency to follow any link that appeared in front of her characterizes her criss-crossing sessions as well. Her choice of links to follow were often not based on any well thought out reason but rather contingent on what was directly available to her. For instance, at the beginning of her criss-crossing session she said, "I chose the standard form just because it is the first on the list." Later when asked why she had not looked at the pyramid table she said, "I forgot about it." When solving problems she clicked around on the pages seeking to find the specific answer rather than deducing the answer from the information provided. As she said, "I'm looking at the spiral table and electronegativity and I can't find the relationship between electronegativity and atomic radii in the standard table so I thought move on to another one. Now I'm looking at atomic radii and basically I'm looking at the pictures they are showing, the diagrams. This isn't helping me at all."

It is interesting to note the relative complexity of Susan's navigational choices as she looked for an answer to the second criss-crossing question (see Figure 11). It seems as if Susan had browsed through a series of tables (and related themes) in order to develop her answer. Her navigational logs for the criss-crossing question in session 2 is the most non-linear navigational pattern showed by any individual. She began in a relatively structured manner (quite like Donald) by going through all the representations for a specific theme. However, with time her navigation became haphazard and focused around the standard representation. Her think-alouds reveal that this seeming non-linear criss-crossing is more a sign of her confusion or lack of understanding than an indication of a well thought through plan of action.

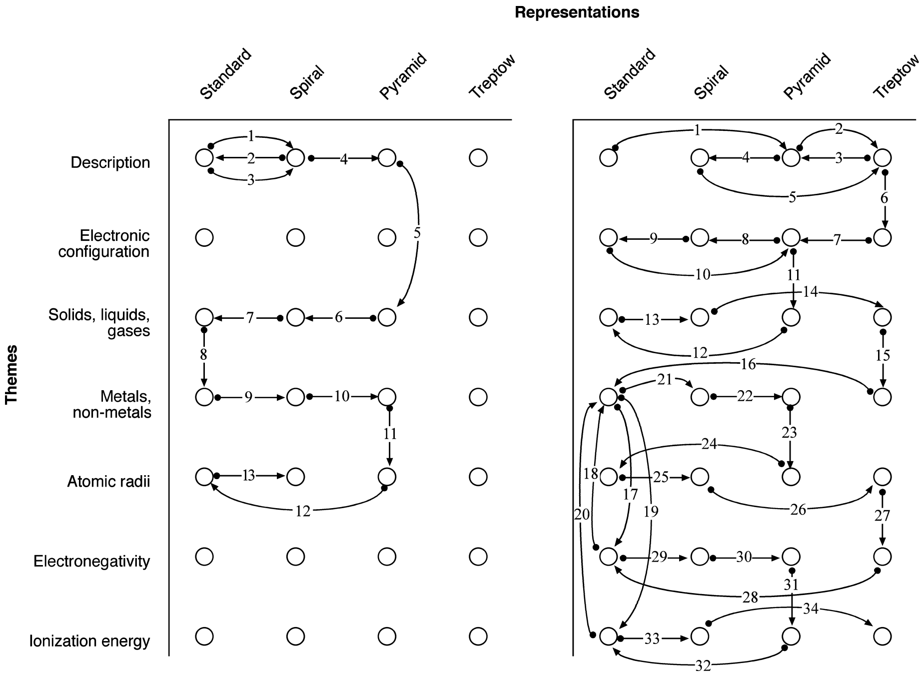

Fig. 11 Sample navigation patterns for Susan. From Session 1 and Session 2

Summing up

Susan learned some chemistry from her interaction with FLiPS. Her test scores (see Table 1) rose from 8 to 22 (out of a maximum of 50). However, most of the increase in points came from direct factual questions. She either left a lot of the short answer, application and transfer questions blank, or got them wrong. Even in the factual questions it was clear that she did not accurately remember what she had read, referring to the Treptow's table as "Trakow's" and predicting the chemical formula for the hydride of sulfur as being H_2SO_4 (sulfuric acid as opposed to H_2S, hydrogen sulfide) and adding the note that "this is a guess, but I remember reading this on the program." However, sulfuric acid was not mentioned anywhere in FLiPS.

She was often not sensitive to the fact that her knowledge of chemistry (or lack of it) was causing problems in her working with FLiPS and answering the questions. She did feel that she needed to read things more carefully. When asked what the single most important thing she had learned in the three sessions she did not mention anything about chemistry but rather said, "That I should read things carefully the first time because I [laughs] tend to skim things over in the beginning and get to the question and realize that I don't know anything and I have to go back and look again." She did not feel that the chemistry in FLiPS was hard to learn and she did admit to finding the questions difficult. She said, "Certain things I found being harder than others but I won't say that the materials were hard but questions I thought were hard, like the questions at the end. I could relate to the materials as I was reading through it and then I would get questioned about it at the end and then I would realize that maybe I didn't understand it all. I just thought I did." She did not think that her thinking about chemistry had changed in any way because of working with FLiPS.

It is interesting to note that Susan was the only participant who was not surprised by the alternative representations of the periodic system. This could be attributed to her fragmented background knowledge. It is only someone who has some understanding of chemistry as normally taught, and represented in textbooks, who would be surprised by these different representations. For Susan, these different representations were just the way chemistry was.

Overall she felt that FLiPS was a "good way" to learn chemistry. She said, "I liked reading through it." However, she added that it would have to be a part of some course for her to really use it. Consistent with her relatively passive approach to learning she added, "But I think it will be hard for me to sit down to force myself to do it. I mean just on my own."

Terry

Background

Terry was a Caucasian, 20-year-old, senior double majoring in music and computer science. He had four semesters of chemistry, two in high school (receiving A in both); and two at the university (receiving a B and an A). Terry scored 4.14 on the Cognitive Flexibility Index, which put him towards the complexity end of the continuum (Table 2). He seemed to have a more complex set of beliefs about the nature of learning and knowledge (4.34) as opposed to his beliefs about the nature of the world (3.5). He described his philosophy of learning as follows, "When I am learning I like to understand the concepts behind what I am learning rather than memorizing information." While working on FLiPS he commented that this was the way he liked to learn because it explained "the concepts behind why the periodic table was the way it is not rather than just what it looks like."

Terry seemed to be motivated more by internal factors than external ones. Learning was important to him because, as he said, "I guess it is just because I like to know things and, I like to understand how things work." He described his motivation for learning as follows, "I guess what motivates me the most is the desire to make myself better. If I see something like a quality and I want to be that way, then that would motivate me, like wisdom."

He described his best learning experience as being "when it wasn't part of the class. [It was] when I was learning how to program in JavaScript and I didn't take any classes, I learned on my own, I just found the information myself and got to do it. I knew what information I wanted and I would look for that information."

Terry had a pretty good grasp of chemical concepts as reflected in his pre-test scores (22 on a total of 50). His knowledge of the periodic system can be seen from his answers to the transfer questions which though not totally accurate do demonstrate a familiarity and fluency with important concepts. His description of the periodic table in the first session saw it as a way of arranging elements "that shows the properties of the elements, like how many protons are in the nucleus and what energy levels they have."

Working with FLiPS

Terry was reasonably comfortable with the think-aloud procedure and had no problems with the interface and thought it was "pretty natural" and "enjoyed it." During the reading sequence Terry continuously compared and contrasted what he was seeing with what had gone before. He reflected on the strengths and weaknesses of the different tables using multiple criteria and concepts to evaluate them. Helped by his background knowledge, he constructed complex arguments when answering on-line questions. He was also sensitive to exceptional cases and refrained from making absolute statements. For instance, when thinking about the relationship between electronegativity and atomic radii he said, "As the atomic number increases the radius gets smaller, *when in the same shell.* I think that would affect electronegativity. I think it probably has something to do with shielding, so when there's more electrons, it shields from the nucleus so that there isn't that much of a positive charge" [italics added]. He quite quickly got comfortable with the different representations and their relative strengths and weaknesses. For instance, after seeing the pyramid table for the first time he said, "This one seems to make more sense to me than the standard table. I think this makes more sense because I mean it serves its purpose better because there is no break with the f elements being separated from the table."

Terry seemed to be involved in a dialogue with the software, co-constructing meaning as though in a conversation. For instance, when investigating the relationship between electronegative and metallic properties he started by looking at the standard table. He said, "On the standard table, electronegativity does not appear to have much relationship because the atomic is radii is large on the left hand side and becomes smaller. Actually, Oh... I guess it is confusing in this table because of the noble gases, looks like here as the atomic radius decreases the electronegativity increases."

At this point he moved on to the spiral table, "So on a spiral table its pretty easy to see, I guess. Atomic radius is easier to see than in the standard table because there's no break between the noble gases and the first row of the table, the first column." And then moving to the pyramid table, "I think the pyramid table, in this respect will be a little better than the standard table because the *f* block is in the table so you can see it and it does follow the same pattern, but other than that it has the same drawbacks as the standard table."

The conversational aspect of his working with FLiPS became most evident during the criss-crossing phase, as he tried to make sense of what he had read so far to answer the online problem-solving questions. He struggled with the concepts, attempting to integrate what he saw on the screen with what he was thinking. In answering a question about electron affinity, he started with the idea that electron affinity would have a pattern similar to that shown by electronegativity but the opposite of the pattern shown by ionization energy. He said, "So I think the element with the highest ionization energy would have the lowest electron affinity, should be Helium and the lowest would be something like Francium, I mean, but this doesn't work." At this point Terry noticed that his reasoning led to two different, and contradictory solutions. He went on, "Lets see. Well ionization energy and electronegativity show the same pattern. I think that the more electronegative and high ionization energy have greater electron affinity, why?" He paused and then abruptly, "Oh! oh! oh! now I understand. I was thinking wrong about the ionization energy, I was thinking that it would take more energy to that if it had a high ionization energy it would take more energy to add an electron but if the ionization energy is high then when it if you adds an electron it will gain energy.... [pause] if there is a higher ionization energy it would be more likely to gain an electron because it would be easier so it would lose energy, since electron affinity is the relative ease so it will have the same pattern as the ionization energy." In a similar manner, discussing the change in reactivity as atomic number increases in the alkali metals, Terry worked through the problem by gathering evidence to support his argument from multiple perspectives, from the point of view of electronegativity, from the point of view of electronic configuration and electron affinity (a concept he had just been introduced to as a part of a problem solving exercise).

Terry was also sensitive to the fact that these factors can play out differently in different contexts. For instance, in the oxygen group he made a similar argument but realized that the results would be the opposite of what he had argued previously. He said, "Oxidation state [of the oxygen group] is minus two, when we go from oxygen to polonium then it would have to gain two electrons and as you go that way it becomes less likely to gain because the

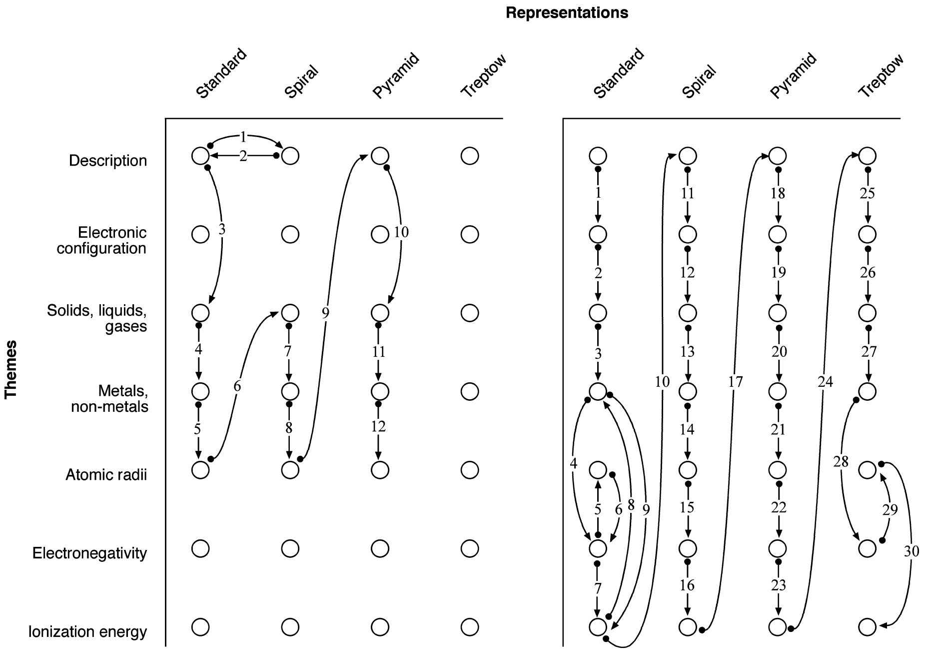

Fig. 12 Sample navigation patterns for Terry. From Session 1 and Session 2

electrons affinity is less so the reaction would be less likely to take place. Because oxygen is more likely to react it is a better way of getting hydrogen."

Terry had a very structured approach towards navigating the different themes and representations in FLiPS (see Figure 12). During the criss-crossing stage, he would check out all the tables and concepts that he felt were relevant and use the information to develop very complex and complete answers. Terry's navigational logs while he was working on the second criss-crossing problem are quite similar to those of Martin. He moved through all the themes for a given representation before moving on to the next representation. Though he did have a bit of a complicated back and forth while on the standard representation his traversal of the other representations and themes is quite straightforward.

Summing up

Terry learned quite a bit through working with FLiPS. His post-test score was the highest of all four participants (38 on a maximum of 50). Table 1 shows his scores by question type—factual, near transfer, far transfer as well as for the complete test. He showed improvement in his answers to the factual and the far transfer questions. His answers to questions were more complete and complex. He became sensitive to exceptions and to the complexity in the periodic system. Interestingly, this awareness of complexity could have hindered him as well. For instance, in a multiple-choice question about the oxidation state of oxygen he went from a correct answer (checking just one option) in the pre-test to an incorrect answer (checking all of the above) on the post-test.

When asked about what the single most important thing he had learned was he said, "I guess the most important is that there are different forms of the table because I wasn't aware of that there were different forms." He did not feel that his thinking about chemistry had changed in any significant way though he did feel that he now knew, "more about it than before."

Terry was the participant who seemed to utilize what FLiPS had to offer to the greatest degree. This was probably due to a variety of factors: his stronger knowledge of chemistry; his focus on understanding the concepts behind phenomena; his appreciation of the power of abstract ideas; his self motivated learning style, as well as his complex epistemic beliefs. So though chemistry was not all that important to him personally he could still take pleasure in the manner in which different representations and concepts were related to each other.

Cross-case analysis: Themes and variations

The four detailed profiles of the participants indicate that there are significant similarities and differences between individual experiences of working with FLiPS. These rich profiles offer us insight into the process by which the design of FLiPS is exploited (or subverted) by the learner. In the next section we will focus on looking across these four cases to better understand what these four participants have to tell us about the working with FLiPS and the process of learning from it.

Working with FLiPS

None of the participants had any significant problems while working with the computer program. In fact, almost all the participants were unanimous in their appreciation of its ease of use and transparency of interface. A measure of their comfort with the interface can be seen in the fact that the "help" function was never used. This "ease of use" can be attributed to: (a) the fact that FLiPS was designed to build on their prior experience with the Web; and (b) the care that went into making the entire experience of working with FLiPS as consistent as possible. The occasional problems that did occur can be attributed to two causes: (a) software and hardware problems in the program itself; and (b) "communicative breakdowns" between the program and the user (Dillon and Gabbard, 1998).

Though "getting lost in hyperspace" (Conklin, 1987; Dias *et al.*, 1999; Jonassen and Grabinger, 1990; McDonald and Stevenson, 1999) is one of the most common problems faced by readers of hypertexts it was not something that bothered most of the participants. The only person that seemed to face this in any significant manner was Susan. There could be a variety of reasons for this. First, her weak knowledge of chemistry made it harder for her to understand many of the concepts being explained. Second, as she herself admitted, she did not read the material carefully and so was not completely sure as to what she was doing at any given time. Also, her clicking on links just because they were there did not help. Her lack or prior knowledge of the content, may have resulted in an higher level of "cognitive overhead" (Jonassen and Grabinger, 1990) as she made hypertextual choices, which in turn would have had a negative influence on the time she devoted to reading and thinking about the information.

Learning with FLiPS

We began this paper with a series of issues that drove the design of FLiPS. The first question was whether working with FLiPS would help students go beyond memorizing facts to the development of a deeper understanding of complex knowledge about the periodic system. In addition, would working with FLiPS help the learner apply that knowledge to new problem-solving contexts.

The first thing to note is the clear lack of knowledge and understanding that most participants showed about the chemistry of the periodic system. All four participants had at least two courses in chemistry at the university level. However, all of them had no understanding of the concept of periodicity. This includes Terry who was easily the most knowledgeable of the four. Their lack of understanding of periodicity can be seen not just in their pre-test scores but also in their: (a) inability to explain the basis for the standard table both in the interview and in the pre-test; (b) inability to understand the structure of the new table (Giguere's table) they were given; and (c) predict the fluctuation of atomic radii with increasing atomic number. Most participants (though Terry was better in this respect) had fragmented knowledge about chemistry in general and about the periodic system in particular. They knew the names of certain concepts and sprinkled them in their answers but were clearly unsure about their meaning. This could be easily seen in the manner in which they would use (and misuse) these concepts while answering the questions.

However, this lack of understanding is not necessarily surprising. Prior research on learning in chemistry (Anderson, 1986; Carter and Brickhouse, 1989) has shown that most students have significant problems in learning fundamental and basic concepts in chemistry. Given this lack of basic knowledge it is not very surprising that students would have problems with advanced concepts as well. What is surprising (or worrisome) is the fact that all four of the participants in this study had at least two or more college level courses in chemistry and had received quite good grades in them.

Given their background knowledge (or lack of it) as well as the amount of time and effort they spent working with FLiPS, it is not surprising to see that all four participants received higher scores on the post-test. The pre- and post-test scores for all four participants (by question type as well as for the complete test) are given in Table 1. Donald and Martin showed the greatest increase in scores (19.5 and 18.5 points respectively), Terry was in between (with an increase of 16 points) while Susan had the smallest increase (14 points). All four participants did quite well on the factual questions (though even here Terry stands out). More significantly, Martin and Terry did the best (18 and 19 points respectively) in the far transfer questions. Susan fared the worst here scoring just 8 points (out of a possible 28). The two individuals with relatively complex epistemic beliefs and with intrinsic motivations to learn fared best in learning from FLiPS and in answering the transfer questions.

Two of the participants Martin and Terry appeared to have focused on the conceptual aspects of the periodic system. This is evident not just through their answers to the post-test questions but also in their interaction with FLiPS. They were more willing to explore the different representations in order to understand the concepts that underlie the chemistry of the periodic system. Their answers to the transfer questions indicate that working with FLiPS did help them transfer their knowledge to new and different contexts. In contrast, Donald seemed unwilling to explore. He searched for the *right* answer and often restricted his search to a single representation (the standard form of the periodic table). His answers to the transfer questions were often simplistic and non-explanatory. It must be added that Donald did appear to have become somewhat more sensitive to the idea of patterns and exceptions as some of his answers to the interview questions (and the post-test) indicate. Susan, on the other hand, seemed lost and though she looked at various representations while developing answers to the on-line transfer problems, her choices were often idiosyncratic and unplanned. She seemed to have picked up some factual knowledge but she did not seem to have developed an understanding of the conceptual intricacies of the periodic system.

The role of individual differences: Beliefs, motivations, prior knowledge

The advantage of rich cases analyses (as in this study) is that it allows the researcher to look closely at the experience of the learner as they interact with and learn from hypertexts. Two key factors that we introduced in the beginning are beliefs and prior learning. In addition, it appears that motivation plays a mediating role as well. These four case studies show that all of these three factors played important roles in the participants' learning, however, the relationship between these factors is not straightforward.

It appears that two of the participants (Martin and Terry) with complex or sophisticated beliefs about the world and the nature of knowledge learned more than the others. Donald's beliefs seem to lie towards the simple end of the continuum and his need to find the "right answer" or the "right representation" seems to have prevented him from exploiting FLiPS to the maximum.

However, Susan's case is an interesting one. Susan had a relatively complex score on the epistemic beliefs questionnaire. However, she did not fare very well in working with and learning from FLiPS. Clearly having a set of complex epistemic beliefs does not necessarily mean that individuals would learn well with hypertext. There were two other factors in Susan's case that may explain her troubled experience with FLiPS. The first was that, Susan lacked any internal motivation for learning. Learning, for her, was a passive activity, driven by the choices made by a teacher. Learning with FLiPS, on the other hand, required her to play an active role, something she may not have felt comfortable with. This lack of motivation to learn, coupled with low prior knowledge seem to have been critical in making learning with FliPS difficult for her. Thus, Susan's weak background in chemistry and her lack of curiosity about the periodic system, hampered her learning with FLiPS, despite her relatively complex beliefs about the nature of knowledge.

Considering prior knowledge, Terry clearly knew the most among the four, with Donald and Martin somewhat similar to each other, with Susan being the least knowledgeable. Despite the fact that Donald and Martin were somewhat similar in their prior knowledge, their individual experience with FLiPS were quite different. A part of this may be due to their differences in motivation and their epistemic beliefs. It seems that Martin's more complex beliefs helped his working with FLiPS. In contrast, Donald, with his relatively simple beliefs, did not exploit the functionalities provided by FLiPS. His need to find the one right answer or the one right representation also hindered his learning. Donald and Martin also differed from each other in terms of their primary motivations to learn. Donald seemed more externally motivated (by getting good grades or the right answers) while Martin was more driven by internal motives (what he labeled as "curiosity"). Susan with her lack of knowledge of chemistry and her low motivation for learning more about it seemed to be least suited to learning from FLiPS and that is exactly what we see. And that is (as described above) despite her somewhat complex epistemic beliefs. Terry with his complex beliefs about the nature of knowledge *and* his strong background in chemistry, and his strong internal motivation to learn, was clearly the person "primed" to exploit FLiPS to the maximum—and he did just that.

An interesting feature that emerged from the analysis is a somewhat surprising relationship between an individual's epistemological beliefs and their navigational patterns through the hypertext. Surprisingly the students who had the more complex navigational patterns (Susan and Donald) were the ones who had the most problems with the hypertext and learning from it. In terms of using FLiPS, Martin and Terry were extremely systematic in their navigation strategies and attempted to extract, compare, and contrast information from a variety of sources in developing their answers. In contrast, Donald and Susan were far more haphazard in their navigational choices. Martin, after some initial exploration, restricted himself to one representation while Susan's navigation became increasingly chaotic as time went by.

To sum up, it seems clear that having some background knowledge of the domain in question is essential for understanding the relatively complex and advanced concepts embodied in CFT-based hypertexts. The students with a weak knowledge of the basics had the hardest time with the ideas and concepts presented through FLiPS. This is consistent with what Spiro and his colleagues (Spiro *et al.*, 1988) have argued in the past i.e. Cognitive Flexibility Theory may be a more appropriate learning theory for advanced learning (as opposed to foundational learning). Our work in this research provides qualitative empirical evidence for this.

However, merely having domain knowledge is not enough to fruitfully exploit the affordances of CFT based hypertexts. The effect of CFT hypertexts on learning are mediated by a range of factors which include, motivation (internal or external), epistemic beliefs (simple or complex), and background knowledge (coherent or fragmented). It appears that having a complex belief system or world-view facilitates a learner's interaction with FLiPS and helps them learn with it. This indicates that CFT hypertexts will not necessarily work with each and every learner. A learner with a more simplistic set of beliefs about the world and the nature of knowledge would not necessarily gain much from such instruction. Such a learner (Donald being a good example) would not explore but would rather focus on one overarching description or framework—what Spiro and others have called oversimplification of the complex nature of the domain (Feltovich *et al.*, 1995)

Similarly, student motivation can play an important role in what they learn from CFT hypertexts. CFT hypertexts by their very nature are open-ended and constructivist in nature, offering multiple perspectives and undermining simple and single "right answers." Moreover, these instructional designs are dependent on learner choice i.e. the learner constructs the paths they would take through the conceptual landscape of the domain. Students like Terry and Martin who are internally motivated, through curiosity and a desire to learn, appear more capable of learning from such media. Students such as Susan and Donald who are externally motivated (either by teachers or by seeking to find the one right answer) may not find CFT hypertext to their liking and may not, thus, engage with the ideas in a sustained manner.

Another interesting finding that emerges from the study is that working with CFT hypertexts may actually force students with simplistic epistemic beliefs to become more aware of the limitations of their perspective. However, for this to happen the student must have some prior knowledge of the domain in question. For instance, there is some evidence to indicate that Donald, though the student with the most simplistic set of epistemic beliefs, may have become sensitive to the nuances and complexities of the periodic system as reflected in some of his answers in the post test. If this is indeed the case, this argues for a more complex relationship between beliefs and working/learning from CFT hypertexts. We have argued elsewhere (Mishra, 1998) that seeking simple cause effect relationships between beliefs and interacting with hypertexts may be incorrect. We provide some evidence to indicate that this relationship may be bidirectional, reciprocal and dialogic; a transaction (Bruce, 1993; Rosenblatt, 1978) between a learner's epistemic beliefs and their process of working and learning from such instructional media. If this is indeed the case, though our data does not provide a distinct answer, this has implications for the design of future CFT hypertexts. It may be that the design of the hypertexts themselves, in some way, "force" learners to explore and to reduce their dependence on standard forms of looking at the domain. In the case of FLiPS this could mean that the design of the system not include the standard table at all (or at least not at the very beginning). It may be that by removing the representational scheme that they are most familiar with, the learners would be forced to look at and work with the other, non-standard, representations, possibly forcing them to confront their narrow understanding of the domain.

A final interesting finding, and a somewhat surprising one, was regarding navigation patterns of the learners as they traversed a complex, ill-structured domain. Those with some prior knowledge, and complex beliefs actually had more structured navigation pattern through the hypertext. In fact, it were the ones with low background knowledge and relatively simplistic beliefs who had the more complicated traversal patterns. This indicates that the complex learners use the software as a "compliant guiding framework" (Mishra *et al.*, 1996) to structure their investigations. Thus complexity in thought is not necessarily reflected as complexity in navigation. In fact the opposite may be the case, i.e. complexity of navigation may reflect a lack of understanding. This is an arena that has not received much research attention and this study indicates that it may be worthy of further investigation.

We must add that the fact that FLiPS was tested in an artificial, experimental situation may confound what we find out about the role of motivation. It is possible that if the same software were integrated into a regular classroom context, students such as Susan, may find it more motivating and useful.

Conclusion

The main methodological argument that underlies this paper is that prior to developing general frameworks of technology usage it is important to explore and identify the manner in which individual learners work with it. As McDaid (1991) said, "of most utility may be participant-observer phenomenological analysis, guided by an awareness of the biases of media" (p. 220). Such research has an important role to play in determining whether "the predicted social and cognitive impacts of digitality [are] borne out in actual practice" (McDaid, 1991, p. 219)

This study indicates that a person's interaction with hypertexts (such as FLiPS) and what they learn through this interaction, is complexly inter-related to their prior knowledge, their motivations for learning and their beliefs about the world and the nature of knowledge. Though each of these factors we discuss (beliefs, motivations, and prior knowledge) have been identified in the research literature as being important in understanding how people learn from hypertext, our study shows that these factors should not be seen in isolation. Thus the findings of this study indicate that even the most thoughtful or theory based design of educational hypertext can be rendered relatively ineffective by the kinds of decisions users make and what they bring to the interaction. Clearly, this interplay of background knowledge, beliefs and motivation has significant consequences for the further development of hypermedia learning environments. Users are far more complex, and as this research shows, vary from each other in different ways and that can have a significant impact on the pedagogical effectiveness of the educational computer program.

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