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USE OF COGNITIVE ARTIFACTS IN CHEMISTRY LEARNING

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In everyday life, we interact with cognitive artifacts to receive and/or manipulate information so as to alter our thinking processes. CHEM/TEAC 869Q is a distance course that includes extensive explicit instruction in the use of a cognitive artifact. This study investigates issues related to the design of that online artifact. In order to understand design implications and how cognitive artifacts contribute to students' thinking and learning, a qualitative research methodology was engaged that utilized think aloud sessions. Participants' described constrained and structured cognitive models while using the artifact. The study also was informed by interviews and researcher's field notes. A purposeful sampling method led to the selection of participants, four males and two females, who had no prior history of using a course from the 869 series but who had experienced the scientific content covered by the CHEM869Q course. Analysis of the results showed both that a cognitive artifact may lead users' minds in decision making, and that problem solving processes were affected by cognitive artifact's design. When there is no design flaw, users generally thought that the cognitive artifact was helpful by simplifying steps, overcoming other limitations, and reducing errors in a reliable, effective, and easy to use way. Moreover, results showed that successful implementation of cognitive artifacts into teaching –learning practices depended on user willingness to transfer a task to the artifact. While users may like the idea of benefiting from a cognitive

artifact, nevertheless, they may tend to limit their usage. They sometimes think that delegating a task to a cognitive artifact makes them dependent, and that they may not learn how to perform the tasks by themselves. They appear more willing to use a cognitive artifact after they have done the task by themselves.

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CHAPTER I

Introduction

Donald Norman (2006) concluded an interview with *Forbes*, with the following words:

> "What tools have had the biggest impact upon civilization? Cognitive artifacts. Tools for the mind."

Modern humans expand their cognitive abilities using symbol systems, external representations and tools. According to Norman (1994) "in today's world, we have taken evolution into our own hands, providing external devices - what I have called 'cognitive artifacts' to expand our abilities beyond that which our biological heritage alone make possible."

Any devices that humans interact with to receive and/or manipulate information in order to engage in a thinking process are considered as cognitive artifacts (Norman, 1991). Symbol systems on calendars, color-coding schemes, the sound of a warning timer, and computers are some examples of cognitive artifacts (Spillers, 2003).

Aiding humans to extend and stimulate thinking capacities (Salomon, Perkins & Globerson, 1991) to overcome limitations in problem solving and decision making (Spillers & Loewus-Deitch 2003) makes cognitive artifacts different from other tools (McGerry, 2005). Because of aiding memory, attention, and information processing, cognitive artifacts improve cognition and utilize the process of thinking, remembering, and problem-solving (Norman, 1991; Hutchins, 1999). Additionally, cognitive artifacts help to minimize errors in task attainment (Hutchins, 1999).

Cognitive artifacts don't change the capacity of human mind. Instead, they change the way of using knowledge and the way of interacting with knowledge (Zhang &

Norman, 1994). Without the help of cognitive artifacts it would be very difficult or even impossible to construct some knowledge and knowledge interrelationships (Hutchins, 1995a).

According to Norman (2006), "These cognitive tools are so essential to civilization that we send our children to school for decades." For instance, computers, (examples of cognitive artifacts) are helping to improve both learning and teaching (Cuban, 2001). In addition, the use of computers in classrooms has increased student learning and interest (Kulik, 2003; Weller, 1996). Once used as passive "page turners," today computers serve as cognitive artifacts to aid student thinking in ways similar to those in which professionals use these tools (Runge et al., 1999). In spite of improvements in cognitive artifacts for learning, integration of these tools within curricula has been underwhelming (N. Bitner & J. Bitner, 2002); daily classroom activities have not changed much (Gifford & Enyedy, 1999; Cuban, Kirkpatrick & Peck, 2001; Wright &Wilson, 2006; Su, 2009; Glifonea & Mayani, 2011), possibly because of cultural beliefs about teaching and the organization of schools (Cuban, 1993).

Many of the artifacts that are used in education are physical and symbolic artifacts such as ink marks on a paper or scientific languages and notations. The use of digital devices and computer systems as cognitive artifacts is increasing, however. New possibilities to aid students in learning environments are emerging. How should teaching practices change so as to enable students to be able to use cognitive artifacts as professional tools? There is a need for understanding integration of computers as cognitive artifacts in education in order to understand how to use them. The current literature has focused on the use of cognitive artifacts in everyday use (Norman, 1993,

1994; Gifford & Enyedy, 1999; Hutchins & Palen 1998; Engeström, 1990, 1999; Bodker, 1997; Streeck, 1996; Pu & Lalanne, 2002; Card, Mackinlay, & Shneiderman, 1999; Hutchins, 1995a, 1995b, 2000; Stahl, 2003; Payne, 1993). Studies investigating the use of classroom artifacts are rare (Ching, Levin, & Parisi, 2004; Sfard& McLain, 2002).

There are essentially no studies describing how best to incorporate the use of cognitive artifacts in learning. Exploring cognitive artifacts in detail can offer insight into the challenges that students may have while interacting with them.

Significance of the Study

Today technology shapes our environments and us in complex ways that are happening with very little understanding and rational planning (Dahlbom, 2002). In his book *The Sciences of the Artificial*, Simon (1996) agues that "man –or at least the intellectual component of man- may be relatively simple, that most of the complexity of his behavior may be drawn from man's environment, from man's search for good designs" (pp. 158).

He also points outs the need of understanding the design of artifacts with the following words:

> "Few doctoral dissertations in first rate professional schools today deal with genuine design problems as distinguished from problems in solid-state physics or stochastic processes" (Simon, 1996 p.130)

Simon also adds that:

> "If I have made my case, then we can conclude that, in large part, the proper study of mankind is the science of design, not only as the

> professional component of technical education but as a core discipline for every liberally educated person" (p. 158). Additionally, artificial science should be a design science where researchers need to be ambitious to describe, understand and explain artifacts use as well as constructing design oriented researches from a user perspective (Dahlbom, 2002 p. 22-23).

Cognitive artifacts (such as computer systems) developed without sufficient research can increase rather than decrease task difficulty (Heath & Luff, 1996). In many cases, computer based cognitive artifacts have been designed to resemble physical artifacts and this lead to more complex and difficult systems instead of easier ones (Jones & Nemeth, 2005). Norman (1991) pointed to the need for understanding how artifacts interact with users within artificial environments and information processing tasks. This is also important for instructional designers so as to be able to understand design outcomes.

How should instructional designers incorporate cognitive artifacts within instructional materials? Investigating how cognitive artifacts contribute to students' thinking and learning processes may help instructional designers, policy makers, and school administrators understand the value of using cognitive artifacts in learning systems. Providing better insight into how teaching-learning activities incorporate the use of cognitive artifacts would help teachers to modify their teaching strategies in order to implement the use of cognitive artifacts.

Purpose Statement

The purpose of this study is to understand issues related to the design of an online course aimed at teaching students to use a cognitive artifact within the context of "traditional" learning content. How these cognitive artifacts contribute to the students' thinking and learning was studied in terms of students' interactions and attitudes. The results of this study can be used to guide the development of instructional systems that include cognitive artifacts.

Limitations and Delimitations of the Study

Limitations are restrictions created by the chosen methodology (Bryant, 2004). In this study, a think aloud protocol and follow up interviews were applied as the main methodology for data collection. During data collection with think aloud protocols, if the tasks are too complex for the participants, speaking and performing these tasks in same time may create a cognitive load problem (Branch, 2000). Fortunately, conducting follow up interviews had overcome this problem and provided additional data for the researcher (Branch, 2000; Fonteyn, Kuipers & Grobe, 1993).

CHAPTER II

Review of the Literature

What is a cognitive artifact?

It is almost impossible to separate cognitive artifacts from neurobiological human functioning and capabilities in industrialized civilizations (Engeström, 1999, p. 29). The way science and culture develop depends on artifacts (Norman, 1991), because they are the physical and mental devices for problem solving and task acquiring (Spillers, 2003; Norman, 1991). Cognitive artifacts enable us to operate beyond the limitations of our mind's capacity because of their service "to maintain, display, or operate upon information in order to serve a representational function and that affect human cognitive performance" (Norman, 1993).

According to Norman (1991), "a cognitive artifact is an artificial device designed to maintain, display, or operate upon information." For example, with the help of cognitive artifacts such as concept maps we are able to build strategies by looking into relationships and patterns in the representations and we then are able to think or operate accordingly. In that manner, cognitive artifacts provide opportunities to convert difficult tasks into simpler ones (McGerry, 2005) by providing new ways of using knowledge and representational relationships that are impossible to reach within our neurobiological limitations (Hutchins, 1995a). Cognitive artifacts change the nature of a task and provide new ways of using knowledge. Ultimately, however, cognitive artifacts don't change our cognitive capabilities and don't enhance or amplify neurobiological abilities (Norman, 1993).

A to-do list, which is a memory aid for remembering everyday tasks or activities, is an example of how we use cognitive artifacts to help us to perform (Norman, 1991). At first,

a to-do list seems to be simply a memory tool that enhances our cognitive capacities because it helps us to remember. On the other hand, a to-do list brings a new way of using information to act on it. With a to-do list we need to perform in new ways where we need to construct the list, remember to consult the list, and be able to read and interpret items on the list. If we don't have a to-do, list we need to remember and plan everything in same time. With a to-do list, we can remember our plans after planning our tasks and activities and constructing the list.

Spillers (2003) gives other examples of cognitive artifacts such as a novel symbol system used on a calendar, notes used to decipher a computer system, a glance backward upon exiting, a checkmark circle or color coding scheme, the sound of a warning timer, a mental note, a novel warning indicating an open or closed state, changes in temperature or sound, and shifts in kinesthetic sensation or visual stimulus.

Even though one can describe and give examples of cognitive artifacts, there are no absolute categorical definitions to describe all of them. Hutchins (1999) explains this within the following words:

> "The prototypical cases seem clear, but the category is surrounded by gray areas consisting of mental and social artifacts, physical patterns that are not objects, and opportunistic practices. The cognitive artifact concept points not so much to category of objects, as to a category of processes that produce cognitive effects by bringing functional skills into coordination with various kinds of structure."

What are the Differences between Tools, Artifacts, and Cognitive Artifacts?

In order to be classified as a tool, a thing should be involved in a human activity (Christiansen, 1996, p. 177). Vygotsky (1978) describes tools as things that have a function of mediation or the output of their usage is mediation. In *Activity Theory*, Vygotsky (1981) used the term artifact in the same way as the term tool. According to Cole (1998) artifacts "are ideal in that their material form has been shaped by their participation in the interactions of which they were previously a part and which they mediate the present." According to Wertsch (1998, pp. 30–31), artifacts are physical objects that can exist across time and space without a need for being used in a task. Waltz (2004) presents artifacts as vehicles for social actions, social arrangement, and political intention where they function to build order in the society and world.

We can classify human activities into two categories: interactions with physical objects and social interactions. The first ones require using tools while the latter ones require using language, (Wartofsky, 1979, pp.16). According to Wartosfky, using artifacts is related to humans' mental models and perceptual schemas. These mental models and perceptional schemas are constructed according to cognitive artifacts' role as mediators of human activity (Bodker, 1997).

In brief, artifacts can be described as technological devices that transform individual minds and change the way of behaviors in society. There is debate in the usage of the terms tool and artifact, however, and there is no common agreement on these terms (McDonald et.al. 2005).

On the other hand, there are clear attributes that distinguish cognitive artifacts from other artifacts.

The first classifiable attribute of cognitive artifacts is in simplifying mental tasks, computations, and perceptions because of their representations that aid memory to access important knowledge or recognize different situations easily (McGerry, 2005). The second attribute of cognitive artifacts is in aids to our memories so as to understand concepts better or recognize them quickly. The last attribute of cognitive artifacts represents different ways of thinking about or performing tasks by changing our way of using knowledge to accomplish those tasks. Examples include: the red flashing lights of emergency trucks and the siren sounds that help us to recognize and differentiate emergency situations; a calendar on our desks that represents dates and helps remind us about the day; and an icon on a computer screen that represents a reminder about an application. Another example includes sticky notes written by hand and stuck onto a desktop monitor to remind us of passwords or telephone numbers. Using paper and pen, calculators, page-turners, a graphical representation such as a map or using emoticon-based messages also can be considered examples of cognitive artifacts.

Cognitive artifacts also have attributes related to socially accept symbolic systems where they have constructed meanings to situations and/or messages on them (Goodman, 1978).

Using Cognitive Artifacts in Science

Norman (1993) asserts that cognitive artifacts are especially useful for aiding reflective thinking where someone uses existing knowledge to make inferences and reasons about situations and tasks. This also may involve distributing one's thinking and information processing over cognitive artifacts (Pea, 1985). In this manner, cognitive

artifacts can be used as external aids to support human information processing (Jonassen, 2010).

Cognitive artifacts bring new opportunities to learning environments by allowing distribution of information processing and thinking, improving cognition, improving remembering, and focusing attention. Using technologically advanced cognitive artifacts in a sense-making approach allows us to create cognitive objects for students to manipulate flexibly, to have intermediate representations (Keller & Russell, 1997), and to create connections among different representations of a problem (Porzio, 1995).

Mediated actions are important to understand the way social settings and culture in the external world shape one's cognitive reasoning to transform symbols into meaning (Wertsch, 1985). The notion that artifacts mediate one's environment is a common viewpoint (Vygotsky, 1978). This notion is valid for education and especially in school environments where social artifacts bring about transformations in mediated behaviors in students' learning both individually and collaboratively (Kaptelinin, 2003; Spillers & Loewus-Deitch, 2003). Transformations in mediated behaviors of students should result in interactions with cognitive artifacts that employ practices for new ways of using knowledge (Gifford & Enyedy, 1999).

The use of technological artifacts in science allows us to accomplish tasks readily that we cannot achieve without them. They provide new ways of achieving outcomes easily and more effectively than by conventional means (Lagowski, 1995). For example, using pencil and paper to conduct manual arithmetic calculations is too slow and insufficient to conduct scientific modeling and obtain different representations of

problems. The use of pencil and paper, therefore, has been replaced by many technological alternatives such as graphing calculators. Graphing calculators aid scientists' performances by providing capabilities for numerical, graphical, and statistical representation of solutions which were previously impossible or exceptionally difficult (bin Azman, 2005).

Using advanced technological devices provides us means for enabling visual and symbolic representations such that students can have mental images that help them to approach problems and organize concepts in different ways (Wilson, 2005).

Using Cognitive Artifacts in Science Learning

Demana and Waits (1998) suggest using advanced calculators in teaching for helping students to gain an understanding of scientific activities as well as to redefine the basic skills needed for these activities. Waits and Demana (1999) also call attention to spending time for teaching the use of these new technological alternatives rather than spending large amounts of teaching time for limiting and dated pencil and paper activities. In this sense, using technology requires teachers to reorganize instruction. The relationship between technical tasks and concept development changes such that students work cognitively on understanding science concepts while delegating technical tasks to cognitive artifacts (Artigue, 2001). When creating this balance between conceptual learning and technical tasks, teachers are encouraged to make use of real world problems where students employ cognitive artifacts to address those problems (Galiano, Dominguez, & Cielos, 2008). In the following paragraph, (Hodgin, n d) explains the

effects of using socially accepted cognitive artifacts in order to create relationships between technical and conceptual works for a microeconomics course:

> "As a tool for learning, the capability of symbolic computation programs to combine graphical, numerical, and symbolical capabilities offers advantages in the economics classroom. For example, a commonly stated objective in many economics courses is to teach students to 'think like an economist.' In microeconomics, this means being able to analyze an event, such as a hypothetical change in the minimum wage, in an appropriate economic model of wage determination that describes the effects of the event on those variables under consideration. At a minimum, students must be able to translate the event from words into diagrams. In some cases, however, diagrams alone are not enough. When a model involves several variables, algebra and elementary calculus are better for tracking the relationships. Students learn to apply economic theory by diligently engaging in this practice of model building. Symbolic computation programs are excellent tools for assisting in this aspect of learning because they allow students to concentrate more on understanding the economic principles behind their models and less on the computational details of their models."

Computers are considered as members of symbol systems (Simon, 1996). They can serve as goal seeking information processing systems. They can provide representations of environments such as mental images. The use of computer software creates possibilities for mental models for solutions to real life problems and for simulation-visualization of abstract concepts (Holzinger, 1997). According to Kulik (2003), using computers in classrooms has increased. The nature of daily teaching activities needs to change, however, in ways where students use their knowledge differently (Salomon et al., 1991). Students not only need adapt to these new ways of using knowledge with cognitive artifacts, but also to become proficient in their use (Merrill et al., 1996). In order to meet these needs of students, instructional designers need to design and implement cognitive artifacts in ways that support students' learning by providing opportunities that require mindfully thinking and manipulating knowledge (Salomon, 1993). In this manner, use of cognitive artifacts such as computers and calculators as symbol manipulators brings opportunities for engaging students in a mindfully thinking process. In addition, use of these kinds of cognitive artifacts in daily classroom teaching and learning is critical to developing scientific knowledge (which also is a cultural product) for students to help them to understand practices and concepts of the scientific community (Vicentini & Redish, 2003).

The use of cognitive artifacts for learning reflects practice in the scientific community. For example, the use of calculators in mathematics courses started with the abacus, went on to slide rules, then scientific calculators, then graphing calculators, and now involves symbolical calculators with expanded memory functions and an ability to use algebraic modes. The result is that students must be able to use knowledge in

different forms (Aspray, 1990; Ceruzzi 2003; Waits & Demana, 1999). In addition, using technologically advanced cognitive artifacts can help students to develop conceptual reasoning, understand different spatial visualizations (Kimmins & Bouldin, 1996), and understand abstract concepts (Leinbach, 1994; Albano & Desiderio, 2002).

On the other hand, because of design and implementation issues, using cognitive artifacts directly from scientific environments within educational environments is neither practical nor helpful for learning all the time. Because of possible one-way-ness, students are forced into a habit of using them mechanically without thinking of other possibilities (Adams, 2006). Issues of design that promote actions without flexibility force usage a defined, pre-structured way (Orlikowski, 2000 p. 409; Paymans, Lindenberg & Neerincx; 2004). Efforts to learn to use cognitive artifacts appropriately exemplify the difficulties of simply incorporating cognitive artifacts directly from scientific environments into educational environments without any modification and adaptation (Nielsen, 1993). Therefore, it is very important to address these issues to help instructional designers and instructional technology leaders to make appropriate design and implementation decisions.

Using Educational Technology in Chemistry Education:

In chemistry, scientists use molecular, symbolic and graphical representations to describe concepts and processes (Arasasingham et.al, 2005). Scientists also spend time collecting and analyzing data, searching for connections, and representing data in different formats and models in order to derive meaning and further information from

data (Kantardjieff, Hardinger, & Van Willis, 1999). It is obvious, modern scientists are familiar with computers to execute numerical calculations and analyze data (Raidy, 1984). If we would like students to be capable of performing similar activities as modern scientists, we should get them to recognize and use computers to obtain better and more accurate results faster than with traditional paper and pen methods (Towns et al., 1998).

Because the use of computers has become essential in chemistry, computer skills should be incorporated across the curriculum (Esteb et al., 2010). In this context, chemists were among the first scientific communities to integrate computers in education. Peter Lykos, a faculty member at the Illinois Institute of Technology, developed a chemistry educational computing project that was among the first examples of computer use in education (Hood, 1994). It is not surprising, therefore, that many examples in the literature relate to using computers and other technologies in chemistry education. The use of computers in teaching chemistry is expanding rapidly (Gulinska, 2009).

Consequently, computers have become reasonably well integrated into chemistry education and have become a very important part of classroom and laboratory teaching (Derting & Cox, 2008). The greatest potential educational benefit of computers comes from their calculation power (Biggs, 2000) as well as their ability to allow multiple representations (Cole & Todd, 2003; Kozma et al., 1997). For example, using software to display atomic and molecular level representations in animations that visualize chemical processes in dynamic motion helps students to understand and make meaning from complex chemistry concepts before they start problem solving (Burke, Greenbowe, & Windschitl, 1998). Studies (Williamson & Abraham, 1995) showed that these kinds of computer animations significantly improve students' performance on logical thinking.

Another implementation of the representational potential of computers is simulating laboratory concepts when real laboratory work is dangerous or impractical. Chemistry instructors can use simulations to provide an environment for students to experience laboratory instruments (for example, see Van Bramer, 1998).

There are many other different ways of using computers in chemistry education. Computers can be used for displaying lesson materials in different multimedia formats and thereby reinforce concepts presented in lectures with tutorials, assessing learning with drill and practice, implementing various problem solving techniques, delivering instruction with different formats, and collecting and analyzing data (Bell, Gladwin, & Drury, 1998). Computers can provide realistic and individual in-class assignments (Morrissey, Kashy, & Tsai, 1995) or laboratory assignments where students collect and analyze data within computers using commercial software such as Microsoft *Excel*™ (Chebolu & Storandt, 2003; Lim, 2006).

Using Professional Software in Chemistry Learning

Microsoft *Excel* is not the only professional software used in chemistry education. Programs such as *Mathematica*™, *Maple*™, *MatLab*™, *MathCad*™ and calculators such as models TI-89, TI-92, Voyage™ 200 (Meagher, 2005; Zielinski, 1998) are used by the scientific community and implemented into instruction. *Mathematica* and *Maple* are interpreted symbolic manipulation software; *MathCad* is symbolic manipulation software like an electronic whiteboard where equations and other visuals represented on screen similar as paper representation (Zielinski, 1998). This software is very useful for modeling chemical systems, handling computational details, and allowing students to

analyze models (Ellison, 2004). Use of this popular commercial software allows reducing technical and mathematical skills required in order to start solving chemistry problems. It helps students to understand mathematically intense chemistry concepts with the help of visualization of symbolic algebra systems (Roussel, 1999). This would support the goal of chemistry education, which is voiced by Zielinski (2004a) to "help students to acquire mathematical skills on a need-to-know basis while emphasizing the elegance of the consequences of mathematical methods for understanding chemical concepts."

In addition, because learning chemistry requires a certain level of mathematical skill, students with lower mathematical skills have problems to find right manipulation or they may have anxiety about their calculations (Goldsmith, 1997). Using symbolic mathematics software, beginners and students with low-level mathematics skills can work with templates to improve their understanding of models and experimental data (Zielinski, 2004b). These templates provide chemical contents thereby allowing students to manipulate data and to present chemical concepts by guiding them to help develop higher order cognitive skills in which they can demonstrate rational, logical, consequential, and evaluative thinking (Zielinski, 2004c). Respectively, studying and manipulating models and problems to apply recently learned knowledge would help students to gain a mastery level (Zielinski, 2002).

There already is a body of literature on using symbolic mathematics software (Zdravkovski, 1992; Ellison, 2004), describing the use of templates (Zielinski, 2003), and effective content delivery and skill building. The use of mathematical symbolic software for instruction is not without problems. Each software program has syntax that must be learned by students and teachers, and they may object to learning that syntax. Also,

integrating new software into chemistry lessons plans can be time consuming for instructors (Roussel, 1999).

Using Cognitive Artifacts in Balancing Equations:

There are several different techniques used when teaching "balancing chemical equations." The inspection method amounts to intelligent guessing. The half-reaction method, which is used for oxidation-reduction reactions by separating the reactions into two half-reactions, involves balancing the half-reactions separately using a very structured but straightforward algorithmic strategy and then combining the two half-reactions. The oxidation number method involves assigning "oxidation numbers" to elements involved in the chemical reaction and balancing changes in oxidation number. The algebraic method uses conservation equations for each chemical element involved and then solving the resulting system of linear equations using matrix methods (Anderson & Bjedov, 2002).

When solving chemistry problems using these methods, manual calculations with paper and pen are cumbersome, especially in oxidation-reduction reactions, as well as in cases where there is more than one reaction equation involved (Smith & Missen, 1997). Matrix methods require either understanding matrix manipulations or being able to successfully employ a series of often cumbersome algebraic manipulations. These skills are either unavailable or "rusty" for students learning introductory chemistry where achieving an understanding of the notion of conservation of atoms is critical. Thus the alternative strategies (inspection, half-reaction, oxidation umber) are usually stressed in

teaching. On the other hand, computers are very well suited to matrix methodologies. Computers can run specialized interactive software (like a stoichiometer software, a problem analyzing diagram software, a *HyperCard*-based software or a web-based software) to balance equations (Kumar, 2001). In addition, commercial software such as *MatLab* (Ohrstrom et.al., 2005), *Mathematica*, and *Maple* have been applied to the chemical equation balancing task (Smith & Missen, 1997). There is one study involving an artificial intelligence (AI) tutor for balancing chemical equations, which creates worked out solutions for equations entered by students and interactively answers questions at each step in solution (Walsh et al., 2002). Any science curriculum, including the chemistry curriculum, should equip students to use information technology based tools for scientific inquiry (van Eijck & Roth, 2007).

StoiCalc* as a *Cognitive Artifact

There is little information how cognitive artifacts interact with users (Norman, 1991) so there are no specific guidelines to perform cognitive artifacts analysis. Moreover, there are no rules or guidelines to evaluate cognitive artifacts in learning.

The specific course being studied is CHEM/TEAC 869Q, a distance course intended for science pre-service teachers on the topic of chemical stoichiometry. Chemical stoichiometry amounts to chemical bookkeeping. It concerns problems such as "Starting with 10 grams each of sodium and chlorine, find the maximum mass sodium chloride that can be produced." This content is included in the middle stages of high school chemistry courses and the early stages of college general chemistry. The "skills" are widely applicable in real-life settings. The CHEM 869 course sequence includes

content and material intended for use by secondary school teachers. This course is unique in that it is the first course in that series to include extensive explicit instruction in the use of a cognitive artifact, *StoiCalc*, which assists in all of those tasks associated with stoichiometry. The tools studied here are expected both to reduce errors and to extend thinking. *StoiCalc* is a cognitive artifact because it utilizes established chemical concepts to apply a series of rules sequentially that are challenging for most high school and beginning college chemistry students (Brooks, 1995).

CHAPTER III

Methodology

This study employs a qualitative research methodology to understand design implications for an online learning environment that employs a cognitive artifact. Qualitative researches are designed for exploring and understanding meaning by engaging research methodologies that honor an inductive style, a focus on individual meaning, and the importance of rendering the complexity of a situation (Creswell, 2009). This qualitative exploratory study was based on combination of observational and heuristic data collection.

This study relies on constrained and structured cognitive models of participants that will be described during think aloud sessions. The researcher's review of related video screen captures, screen shot images, audio transcripts, and cognitive artifacts enabled analysis (Creswell, 2009; Patton 2002). In order to document the activity and interaction, the researcher used field notes that may include added analytic comments (Luff, Hindmarsh & Heath, 2000).

IRB Approval:

This study has been approved by the UNL Institutional Review Board (IRB, 20110411632EP).

Participant Sampling:

This study uses purposeful sampling aimed at selecting individuals likely to uncover the range of reactions of early and mid stage professionals (pre-service science teachers and graduate students with chemistry background) to illuminate the central

phenomenon of cognitive artifact use (Creswell, 2008, p. 214). Recruiting was through solicitations made through science education faculty and graduate school.

A main characteristic of this qualitative study is to attempt to discover multiple perspectives of cognitive artifact use. That is, an attempt was made to choose participants with a range of interests and levels given the fact that all will have core notions about the topic being studied. Thus a maximal variation sampling strategy is a purposeful sampling strategy in which the researcher samples individuals that differ on some characteristics or traits (Creswell, 2008, p.214). As typical in qualitative studies, a small number of individuals are selected because the researcher's ability to provide deep understanding decreases when a large number of participants is studied (Creswell, 2008, p. 217).

With six participants, it is possible to conduct a think aloud strategy effectively in order to evaluate users' reactions toward the interface (Nielsen & Landauer, 1993; Jorgensen, 1989; Monk et al., 1993). According to Nielsen (1994), between three and five participants are sufficient for think aloud. The larger number used here reflects the fact that not just an interface but also an entirely new concept, the cognitive artifact, was being studied.

Recruiting Participants:

The CHEM869Q course targets high school science and chemistry teachers, and is offered at a distance. In order to study the actual use of the materials, an audience of science pre-service teachers (n=3) and graduate students (n=3) was recruited using the incentive of a $60 payment for about 3 hours of effort. Participation in the sessions was voluntary, and participants were free to withdraw any time. Six participants were

recruited for the study. The participants included 4 males and 2 females who had no prior history of using a course from the 869 series. They had experienced the scientific content covered by the CHEM869Q course, however. They hadn't experienced the pedagogical content, or they had any experience with the included cognitive artifact (*StoiCalc*) designed for that course. They were expected to have facility using desktop computers. Perhaps most important, they demonstrated an ability to express their thinking, attitudes, and reactions toward the online course and the related cognitive artifact during a preliminary screening session.

In order to recruit participants, a person other than the researcher attended a pre-service teacher class session, described the experiment, and distributed a descriptive brochure. In addition, invitation e-mails were sent to target candidates. The brochure and the e-mail invitation described: the study objectives; why and how candidates would be selected; how the results would be used; study risks and benefits to the participants; protection of participants' privacy and records; participant's roles; duration of the sessions; the number of sessions; compensation payment; and researcher's contact information. Finally, a link to a short video example of a think aloud session was sent to the candidates in order to demonstrate what participants would have to do during the think aloud sessions.

The candidates received a consent form (Appendix A) and a form soliciting demographic information centered mainly on their prior study of college chemistry and their use of online course materials, if any (Appendix B). Based in part on the demographic information provided, in part on gender selection with a goal of having two or three male candidates among six selected candidates, and in part on first come first

served, some of those who responded called to participate a 15-minute screening session where they participated in a think aloud session. This small think aloud session helped to assess a candidate's ability to express her/his thinking, attitudes, and reactions to any online cognitive artifact. All the candidates participating in screening sessions were paid $5. This process continued until six suitable candidates had been identified. Once selected, a prospective participant was sent another invitation to schedule the three study sessions. The $5 payment was not a part of any subsequent $60 compensation.

Participants Benefits:

There were no direct benefits to participating in this study other than a possible increase in core chemistry abilities related to this content. Participants also received a stand-alone copy of the *StoiCalc* software at the end of their participation.

This research study was expected to help instructional designers, policy makers, and school administrators understand the value of using cognitive artifacts in learning systems.

Data Collection:

Multiple forms of data were collected to address the research questions and the variety of data forms supported and verified each other. The data collection included distorted audio records for think aloud sessions and audio records for the one-on-one and face-to-face direct interviews. Also included was the complete and extensive computer record developed by the participant as s/he uses the course materials. A summary of multiple forms of data collection is provided at Table 1.

Table 3.1 Multiple Forms of Data Collection

Data Collection Form	#1	#2	#3	T #4	#5	#6
Think Aloud Audio Records	Audio	Audio	Audio	Audio	Audio	Audio
Think Aloud Screen capture Video for Interactions	Video	Video	Video	Video	Video	Video
Interviews	Audio	Audio	Audio	Audio	Audio	Audio
Field Notes	Text	Text	Text	Text	Text	Text
Demographic Background Form	Text	Text	Text	Text	Text	Text

Data Collection Protocols:

The data collection protocols consists of think aloud sessions, follow up interviews, demographic background data forms, and researcher field notes. Data collection protocols' steps and types of data collected in each protocol are summarized in the following figure.

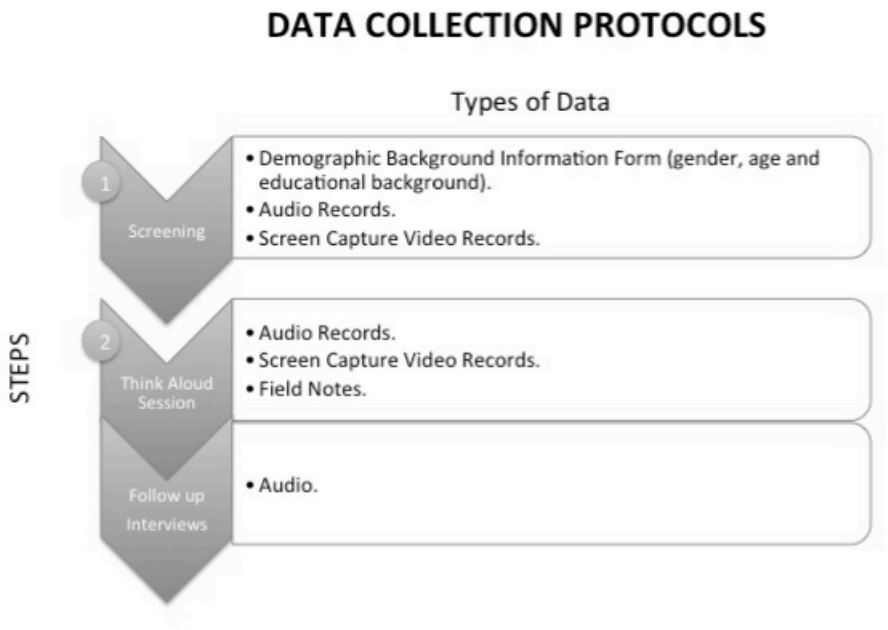

Figure 3.1 Data Collection Protocols

1. Demographic Background Form:

Prior to being invited for a "pretest," participants completed a demographic background form that was used in the sampling process (Appendix B). This short demographic background form includes their gender, age, educational background, and extent of prior study of stoichiometry.

2. Description Protocol:

The think aloud and interviews were conducted in a laboratory set up for data collection purpose. The participants were greeted upon arrival at the laboratory. To make the user comfortable during the think aloud session, the researcher offered snacks and drinks. The conversation was voice-distorted audio recorded. The participants were reminded of the study objectives and procedure. Their questions were answered.

3. Think aloud Protocol:

A think aloud protocol was used to understand users' interactions with and attitudes toward the cognitive artifact (Virzi et al., 1993). In this protocol, participants were asked to talk about their thoughts, reactions, and opinions while interacting with *StoiCalc*. The validity of the think aloud protocol derives from the fact that the think aloud is a direct measure of the real events and what is happening in a participant's working memory (Dumas, 2001). Think aloud protocols are very good tools for obtaining qualitative insights into the user experience (Dumas & Redish, 1993).

During each think aloud session, the researcher also had the role of moderator. As a moderator, he was intervening employing probing questions to focus participant's attention on specific areas and to clarify their explanations (Kuniavsky, 2003). He took field notes while talking with the participants.

While participants were using the cognitive artifacts, their interactions and movements within the learning systems (mostly mouse actions) was captured into a video file using screen recording software (*Camtasia* for Mac).

During the think aloud, the researcher asked probing questions as participants use a specific part of the cognitive artifact (*StoiCalc*). He also asked how they reacted to particular incidents when using *StoiCalc*. He tried to focus their attention on explaining their thoughts and reactions rather than their feelings and opinions. The think aloud protocols for each individual was between 30 – 45 minutes in average.

The researcher explained the procedures of the study and reminded participants that they may withdraw at any time, but that payment depended upon completing a

session. He asked participants to review the procedures of think aloud methodology. He asked them to check if they understood everything correctly before starting the think aloud sessions (and also the subsequent interviews).

4. Interview Protocol:

All participants were engaged in interviews after they completed the think aloud session. The interviews were semi-structured. The interview began with an icebreaker question followed by five main questions that are also sub-questions described in the research plan. Some probing questions also were used in order to get more detailed explanations from the participants. The interview was finished with an end question and a final thank you statement. All the questions in the interview were open ended.

Interviews were about 10 – 20 minutes in length and they were audio recorded with a digital recorder.

Recording and storing data:

During the think aloud session, participants' responses were recorded in a *Camtasia for Mac* video file. Shortly after recording, the sound track was distorted to make recognition of the participant's voice impossible. The face-to-face interviews were audio recorded using a recording device. The researcher reviewed the interviews, transcribed them into text files, had the transcriptions verified, and then destroyed the audio recordings.

Equipment and Settings:

In this study, users interacted with *StoiCalc* using a desktop computer (Macintosh iMac, 27" screen, Intel Core i3, 4 GB RAM) running under MAC OS X 10.6. The software included were *Firefox* 3.6, *Camtasia* software for audio and video screen capture, and a stand alone version of *StoiCalc*.

Other audio from the sessions before and after the think alouds was recorded on another audio capture device. Both the computer and the audio capture device were connected to tabletop microphones that were placed close enough to record each the participant's and moderator's voices. Participants sat in front of the test computer (see Figure 2).

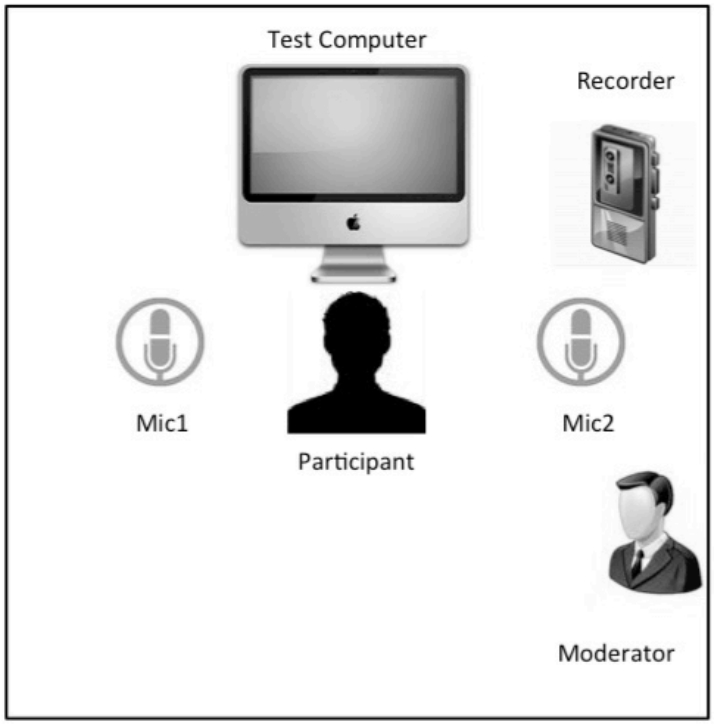

Figure 3.2 Test Room Equipment and Settings

In the test room, the moderator (researcher) was located a few feet from the participants at a 45 degree angle where he could see and interact with participants

closely. The moderator was not so close as to provoke anxiety (see Figure 3.2). As noted, snacks and drinks were provided in the study area.

Data Collection Procedure

The data collection procedure includes obtaining consents and demographic information from all respondents, a pretest session from some of those respondents, and 3 different think aloud sessions and follow up interviews from six selected participants (See Figure 3.3).

Screenings:

In order to identify representative participants, a 15-minute screening session was conducted. Screenings determined participants' ability to express their thinking, attitudes, and reactions toward any cognitive artifacts. Prospective participants were identified on the demographic information and first come, first served as already described. Each prospective participant was invited to attend a screening session in order to be considered as a participant. During the screen, a prospective candidate was asked to perform a small demonstration think aloud session. Participants were introduced about performing think alouds before the demonstration. At the end of the screening session, the prospective candidates were handed $5.

Selection:

After the screening session, the researcher decided whether the prospective candidate was acceptable. Screenings continued until a total of six participants had been identified. The researcher announced the decision through e-mail. Selected candidates were invited for the study.

Think Aloud Sessions and Follow-up Interviews:

All the invited participants were asked to join in the study that a series of three think aloud protocol and follow up interviews. All three sessions started with a think aloud session and ended with a follow up interview.

Before the participants' arrival, the researcher set up the room that contained a computer for the test and audio capture devices (see Figure 3.2).

Once the participants arrived and were ready, the researcher started the session by reminding the participants of the study details and asking them for questions. Instructions about the think aloud technique were reviewed at that time. After that, participants were presented a brief introductory video about the use of online system and of the cognitive artifact, *StoiCalc*.

Each of the three think aloud sessions followed a different, set protocol described in Appendix C. These parsed the *StoiCalc* tasks according to increasing content difficulty.

When the think aloud session ended (participant completed the tasks), a follow-up interview took place in order to get more detailed explanations from the participants. The participants' feelings were solicited at this time.

After the interview, researcher thanked the participants for their support and asked if there would be any additional comments.

Participant Payments:

Upon completion of a session, the participant was offered $15 compensation. They were afforded the opportunity to wait until the end of the last session when they received $60. The full $60 was paid only upon completion of three sessions, and all the selected participants finished all think aloud sessions and interviews.

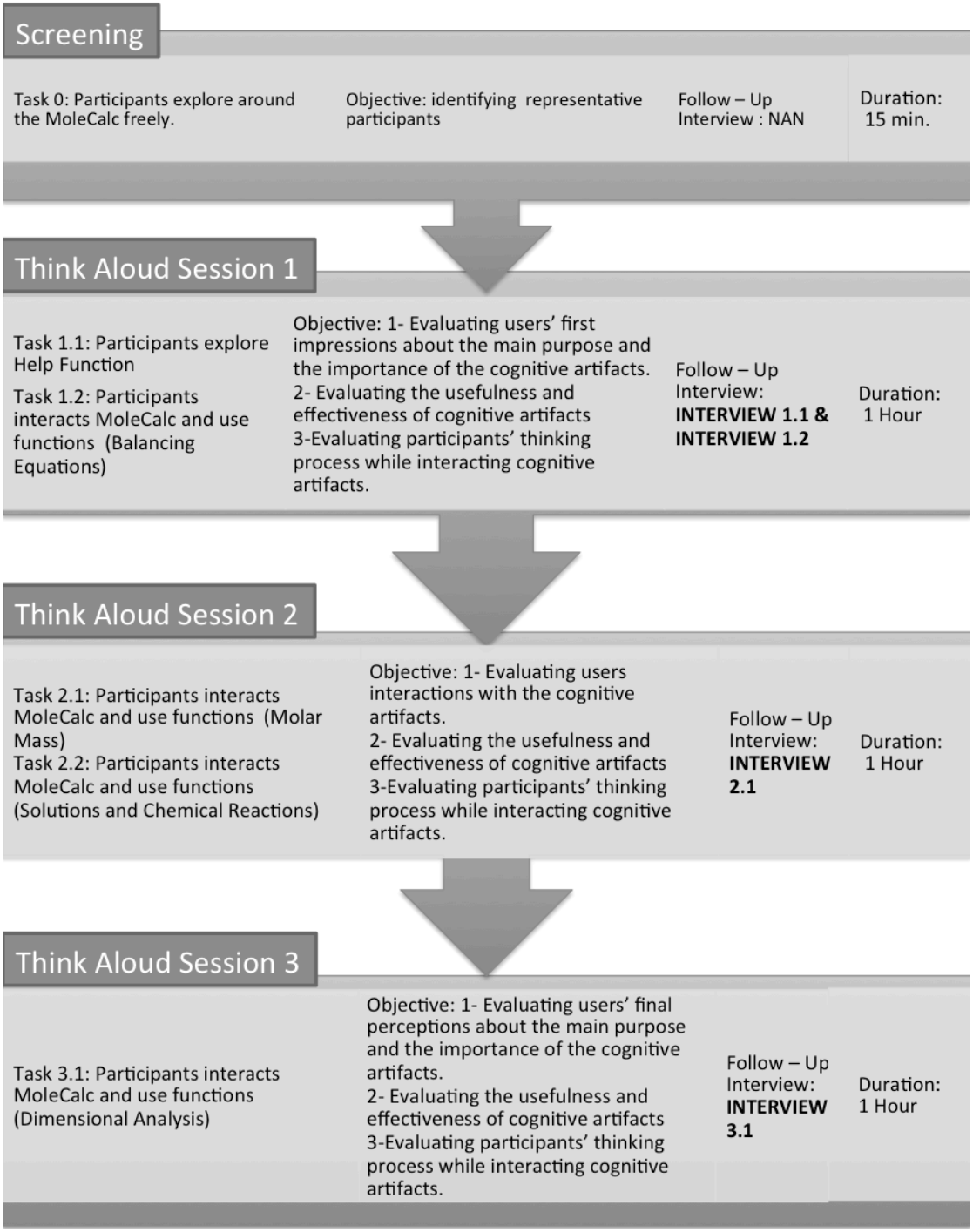

Figure 3.3 Data Collection Procedure.

Field issues:

No major difficulties in the field were occurred during the data-gathering phase. The cognitive artifacts were accessible and no access permissions are required. Because the participants were volunteers, there were no free-choice obstacles. While moderating the sessions, the researcher was following the guidelines for the think aloud protocol.

Reliability Procedures:

The recommendations of Gibbs (2007) were followed to check reliability in this study. A trained researcher verified a random sample of transcripts. Codes were double-checked to be sure there is no drift. An independent researcher (auditor) is paid to read the themes and codes, and to check for irrelevancies.

Validation Strategies:

Data sources were triangulated to check whether the findings are consistent. The interview transcripts and think-aloud session transcripts were examined to determine whether they are consistent with each other. The videos and think-aloud transcripts compared to check for validity.

Participants were contacted by e-mail and they confirmed for member checking using a first draft of the findings. The entire data set for each participant was made available for review. They were asked about the need to comment or add anything. They didn't recommend any major changes in transcripts.

Finally, the think-aloud protocol was consistent with the interviews. Dumas (2001) indicated that this is a natural outcome of think-aloud protocols. He adds that the

validity of this protocol results from being a direct measure of the events and participant's working memory.

CHAPTER IV

Results

Introduction

Users were presented with typical chemistry problems as if they were students in a general chemistry course that makes use of *StoiCalc*, a cognitive artifact or tool designed specifically to help in chemistry problem solving.

StoiCalc directs users in chemical problem solving steps. It focuses them toward a path of problem solving steps by providing screen-based interface options. In addition to *StoiCalc* itself, clues in the questions suggest paths in the problem solving process.

If the users cannot express themselves appropriately within *StoiCalc*, if they cannot understand *StoiCalc* expressions, if the *StoiCalc* interface cannot direct them in problem solving steps, or if users cannot understand and follow the *StoiCalc* interface steps correctly, then confusion, interruptions and failures in problem solving procedures can result. Therefore, interaction and interface design becomes very important to the problem solving process.

In order to understand the problem solving process and users interactions with *StoiCalc*, user think aloud sessions were analyzed and interpreted. In reporting these, minor edits have been made in the utterances that preserve the sense of the response but enhance their readability.

Data Analysis

As a first step of the data analysis, videos of think aloud sessions, interviews and researcher notes were transcribed. After that, think aloud session and interview transcripts are reviewed. Finally, videos were watched again to make sure they are consisted with the transcripts. In this process, in order to obtain a ‘general sense’, it has

been tried to make a general sense of all the data and to see the impression of the overall depth (Creswell, 2009, p.185).

Coding Procedure

In order to bring meaning to information, all the data were organized into segments and chunks. In this process, *NVivo 9* qualitative analysis software was used to code data. This software gives a chance for analyzing material from video files directly. In *NVivo 9*, videos of think aloud sessions were watched with a synchronization of transcripts. The coding procedures were done consistent with the *NVivo 9* software, so the data parts were coded into free nodes at first. Also, in *NVivo 9* coding approach was utilized where there were participant's wordings possible to code. Moreover, additional notes and memos were created while reading the transcripts. In the coding procedure, the goal was to identify categories of data and gather them at a single category. In order to do that, a list of topics as nodes was created in *NVivo 9* and the similar ones merged together. After that, all the codes were reviewed to find a good descriptive word for each code category and to build themes. After a theme list was created, it was examined to determine whether there were very similar themes to merge down into a single new theme. Finally, a trained researcher verified the random sample of transcripts, and she double-checked codes to be sure there were no drift. The trained researcher (auditor) also read the themes and codes, and checked them for irrelevancies. Finally, the theme list consists of following themes and subthemes:

1. **Questions Lead the Mind**
2. **The *StoiCalc* Interface Leads the Mind**

    2.1. Understanding *StoiCalc* Interface Scheme

Questions Lead the Mind:

Reading and understanding the posed question is the most critical step of problem solving. Deciding what strategies to use, where to start, which methodology or algorithm to use, and what functions of the artifact to use depends on one's understanding of question. If the questions are misinterpreted, the user may start from an inappropriate point or may choose a misleading strategy to engage the problem. Signals or cues like wording and the variables asking in the questions can help us with a decision making process. These signals or cues can lead our mind when we need to identify strategies, starting points, methodology or functions of the artifacts.

The process of problem solving using *StoiCalc* started with interpreting the meanings in the questions and tasks. In order to identify their starting point with *StoiCalc*, participants paid attention to the clues and some of the key words in the questions. This also helped them to recognize the available options in *StoiCalc*.

After reading the questions, all the participants tried to find some clues about the starting points before engaging *StoiCalc*. Nearly all participants attended to some of the wording in the questions to identify the appropriate function to use. Directions and explanations given in the about tab or the labels of tab bar (navigation menu) matched some key words in the questions lead the user in identifying the necessary functions to use.

> **User 05:** Well this question is requesting solutions. The "***Solutions***" tab seems like a good place to start to find the mass for this.

> **User 02:** So the first of two questions are asking me... [Reading question aloud].

So, looking at *StoiCalc* I am going to assume that chemical reactions are (at) this tab [click "*Chemical Reactions*" tab].

User 0: I probably click different buttons on the top ["*Tab Bar*"]; I may go sequentially to start as what it tells me. I will start about and I am assuming it will let me something about how to use the program, how to enter data and explain me each of the sections. So I will click "*About*" [click "*About*" tab]. Ohh. I am back to where I started ["*About*" tab]. And there are descriptions given again, each of the things that are available.

In the solutions function of *StoiCalc*, there are two functions titled clearly as "Pure Solute" and "Diluting Stock Solutions." These two functions are presented in the same screen. It may be confusing to select the appropriate one. Matching the wording in the question to the title of one of these two functions directed some of the participants to identify their starting point in the problem solving process.

Researcher: [There are] two red boxes [on the screen], why did you start with the fist one?
User 02: Because I knew that these questions were not dilution problems so in preparations my best bet was the left one.
Researcher: How do you know it?
User 02: Yes, the question does not ask dilute.

Researcher: You just started problem using the first red box, why?

> **User 01:** I knew, I could tell this is [a] pure solution not diluting stock solutions I was preparing. It was asking me to find mass. If the question says like you have a concentrated stock solution of 400 ml of KCl then I would use the right box. It was very clear to me where I need to start and what I will need to do. Even if ["*Pure Solutions*" title] wouldn't be in the left I still would have known. The red boxes are clear to my vision what I would need. There was really no question in my mind what I was supposed to be doing.

In addition, the adjectives known and unknown in the questions give some clues to users. For example, in the solution function, the number of available input fields for entering known variables in order to solve the problem helped participants to identify their starting points.

> **Researcher:** [There are two red boxes in the "*Solutions*" tab] Which part are you going to use?
> **User 03:** Probably I will use "*Diluting Stock Solution*" [box] because it says there are 2 solutions to be mixed together. Two solutions have different concentration. There is a stock solution and a final solution of this stuff. It should have more options [moused over input fields so meaning the input fields] for volume and concentration here, so diluting stock solution may be the way to solve this. So I will check the online manual to see. [Went to help and read aloud].

On the other hand, not all the signals and cues in the question are helpful to identify appropriate starting points or functions. Some signals and cues can be

misunderstood by the users or they can be misleading for them, especially those users having attention problems. For example, some of the users attempted to input the variables directly as they are given in the questions without attending to using significant numbers in the calculations.

> **Researcher:** Why did you put 0.45 in the "*Concentration*" box [input field]?
>
> **User 01:** Because that is what the question asks for?

Moreover, question wordings misled some of the participants in identifying and using appropriate functions and options available in *StoiCalc*. For example, some users had difficulty identifying combustion reactions because there was no direct wording in the question. These participants used *StoiCalc's* equation balancing function without benefiting from the short cut of the predict combustion products option.

> **Researcher:** You didn't use the "*Combustion Products*" button. Why?
>
> **User 01:** Mmm…. Because I didn't know I needed to use it. [According to the question] I think I need to balance the equation so I assumed that I am not combusting anything.
>
> **Researcher:** Is that because of wording in question?
>
> **User 01:** If the question says combust I would use it.

Cognitive artifacts for learning should help users select a starting point. If users choose an inappropriate direction, it becomes problematic. The cognitive artifact should provide available options to start as the first step. For example, in the solutions function

of *StoiCalc*, users were successful in identifying an appropriate function because of clear labeling or the number available input fields. On the other hand, in the balancing function, they had trouble identifying the reaction type to start with. Therefore *StoiCalc* should provide a selection procedure for available reactions tab as a first step.

The StoiCalc Interface Leads the Mind:

Cognitive artifacts interact with our minds. As a result of this interaction, our usual way of thinking may change. For example, cognitive artifacts lead our minds by modifying the steps required to accomplish a task. They can also change the way of our thinking completely by providing a different method or algorithm to accomplish a task. They can simply use the same steps we might use without them, but remind us of those steps or paths that leading to successful task completion.

In *StoiCalc*, schemes are provided through the interface that restricts the possible interactions. Users simply engage interactions with the interface to follow these schemes to reach a result. The *StoiCalc* user interface provides these schemes using on page directions (instructions), labels, tool tips, examples, and layout templates. In addition to these items, *StoiCalc* also supports users by providing a separate on-line, Web-based help option that contains instructions for using the tool. This includes text, video and image formats.

The *StoiCalc* interface interaction and how it leads the users' mind is described in the following sections below.

Understanding StoiCalc Interface Scheme

User 04: If we can change the layout of the boxes [in "*Reactions*" tab] it will be good. You need to design the fields in students' way. Because, I think it is not same as what they are thinking. It needs to show some directions to tell them where they need to enter. Maybe they will be more confused like me, because I entered here in [the blue box for displaying the final balanced equation], because it comes first. Maybe you should change design.

Researcher: What do you mean about the way of students' thinking?

User 04: A user of the software may be not thinking in the same way as the designer. They may think where they should enter and where they can find the result.

When *StoiCalc* provides the scheme for the problem steps, it helps users to understand what they need to do.

Researcher: Do you think the software helps you to remember some concepts in chemistry?

User 04: It reminds me a lot.

Researcher: Would you able to solve these problems without the software if you forgot these concepts?

User 04: No I can't. I think. This software gives us a clear way to find how to do the problems and calculation even though you forgot and just don't know the equation.

User 02: … I know how to do all of these things but seeing it in the program reminded me how to do them….

…

I was thinking that I would go to through the steps in correct order without skipping any important ones. But it is easy to figure out which step I was skipping when it doesn't work.

When the interface design doesn't direct users, they may feel lost. It is very critical to see the correct way of operating the interface. Otherwise there is confusion and frustration:

User 0: I guess the most intuitive off all of these [functions] is the "*Molar Mass"* and the "*Balance*" [tabs]. The rest of them are fairly confusing. I probably needed to be taught something about this software, but I do need anything to be taught about molar mass and balance; these are relatively intuitive but the remaining is confusing. I am familiar with all these concepts, but I don't know how to use this software.

User 01: So that's not clear to me if I was supposed to type in the balanced equation or if I just supposed to type in the reactants and products. And then… umm… it was given two different scenarios. Let's keep reading; here it says enter reactants and products [reading the manual]. Maybe I was not supposed to put in the coefficients; I was supposed to balance it first. And then it wouldn't give me the balanced equation up here. [Keep reading the manual] Ok. I think, I yeah, it was just... I think I know what I need to do now. It was just not clear to

me when I was on that screen that's what I needed to do. I figured since I was given the coefficients I can go ahead and type those in…

User 01: [at "*Solutions*" tab]… Umm. I am not sure. I am just … umm. I wasn't clear. It wasn't clear to me what those were umm I don't know ….
… Nothing's happening there. So I am kind a loss what I am supposed to be doing in this screen if I haven't entered it right or I need to be looking for something different or what. [Silence]
Researcher: What do you think about this situation?
User 01: Well… Mmm. [silence] I think like as a student I am just kind a like well it didn't work I don't know where else to go. Like how would I know what I am supposed to be doing umm at this point in time? Umm. I guess I can go back and look at the mixture I am doing it right so that [click several times] it is not letting me click on that [click several times] I was going to look at it to make sure I am entering stuff into right fields. But now I can't. [Click several times] click on the about and I don't know what to do

Poor interface design doesn't mean that users become completely lost. They may find their ways after a trial – error period, or they can reference their previous experiences with the artifact.

Researcher: Can you explain these pink and green boxes to me?
User 05: It is not immediately clear where you should put your formula, how it should be entered. Just a coefficients label over the left hand column, reactants and products label over the pink and green boxes would be useful. I guess you

should assume reactants come first in this but. Again not immediately clear to me.

User 05: I wouldn't have any idea to input into blue box, I wouldn't know about the reactions arrow, I wouldn't know how to input that.

Researcher: Did you learn how to input by the help page or by your experience with the program?

User 05: I learned it by the "*Chemical Reactions*" [tab]. It is formatted similarly but it has labels. I assumed that this "*Balance*" [tab] is formatted in a similar way and the help page confirmed me. When I have done the "*Chemical Reactions*" [tab] before, it was formatted similar like reactants – products with the pink and green boxes.

With an improved interface design, artifacts may lead users successfully. Moreover the design of the interface with cues and signals on screen present a scheme to users in decision making processes. The interface design affects users' minds to follow a structured steps or path by providing a certain way of interaction. These schemes are presented in interface design of *StoiCalc* within the objects like on screen directions, labels, tool tips, examples, and layout templates.

Researcher: If the designer put "*Mass Products*" buttons before the "*Find MM, REM*" button; would you prefer to click on "*Mass Products*" button first?

User 05: Yeah I think people would probably. If you order it form left to right as I am using it. If you swap those, people will be clicking on them because it is how it displayed on the screen.

> **Researcher:** If you were learning this, would you have confused the steps if the buttons order are not like the process you do?
> **User 05:** I am sure you could. It is not clear. Also, you should line up "*Mass g Before*" and "*Mass g After*" [titles] with the "*Mass Products"* button. It will be clearer with someone who is learning this, I suppose.

The internal algorithms and the paths for internal working procedures of *StoiCalc* are well-structured enough to build certain schemes for user steps to operate. In order to accomplish tasks, users do several well-defined key steps in *StoiCalc*. This nature of *StoiCalc* gives the opportunity to design a well-defined task execution scheme in the interface.

When users had a task at hand to do using *StoiCalc*, the first thing they thought would be to know where to start. Therefore, the very first job of interface of *StoiCalc* should be to lead users mind to select and/or attend to a starting point. *StoiCalc*'s About Function and Help pages may be a good starting point for the users. Also, questions can give clues about where to start.

> **User 01:** [Answering Interview 3.1; question 1] It was fairly easy once I figured out how I needed to approach it. As I keep telling you before, it wasn't clear to me what actions I needed to take as where is I need to put something or what was going to be put by the program. Once I looked up to the web manual and figured out exactly how I was supposed to approach this function of the program, it was fairly straightforward. Only difference was when I was trying to do the milligrams, it is still not clear to me. I am guessing I needed a way to convert on my own.

Researcher: Does the "*Conversions*" [tab] make it difficult?

User 01: Yeah, it was a little bit difficult just not knowing the way of conversion. Actually, you know you need to convert somehow but within the program I cant convert my grams back to milligrams. That part was difficult.

Predefined examples given in *StoiCalc* provide another good starting point for users. In some of the functions, there are pre-defined examples that users can select from options drop down menus. When a user selects one of the examples, *StoiCalc* automatically fills the data given in the examples into the input fields so users can work on that pre-set data. After *StoiCalc* fills in the fields, users should click an action trigger button to calculate a result. Having pre-defined examples also helps users to understand how to operate in *StoiCalc*. It also seems that users can benefit from examples to start work on *StoiCalc*. These examples gave them a clue or starting point. When participants had the examples to wok on, they operated more confidently and figured out *StoiCalc* more easily. As soon as they realized there were examples in some of functions, participants started to use examples to understand what the functions do as well as to have clear starting points:

User 0: Let's see what "*Balance*" [tab] shows me. "*Balance*" [tab] has this feature… [Reading description].

[Click "*Balance*" button]… Enter formula, balance equations, combustion products [reading items titles on the screen]…

That is good, there are examples, and I am going to see one. Water formation that is the easiest thing that I know. [Click "*Examples*" menu, select "*Water*" option]…

H + O give you the water that is good I see something happening here… Ok that is good, I have figured it out. Let's try different one. . Let's try silver nitrate and NaCl [try another example].

That is a nice description. Let's see what I get when we balance it. [Click "*Balance Equation*" Button]. Procedure is given, matrix is shown. This is good.

User 01: I am going to click on the examples; I am guessing that will bring chemical reactions so we can try balancing them. [Click to "*Example*" button]... Ok, it gives me a list here. [Moves in the list items.]… So I am just going to click on the water formation….

User 0: [At "*Solutions*" tab] let's see we get. I have a concentrated reagent here [click menu "*Concentrate*d *Reagents*".]

Oh…wow. This has all bunches of possibilities. Let s see if I can find my NaCl.

No, not here. I will type in my NaCl. .

Also, when there were no pre-defined examples and data sets to work, users may have difficulty understanding what is going on at the interface. Some of the participants expected to have pre-defined examples in the functions that they didn't understand how the interface works.

User 04: [click to "*Conversion*" tab, mouse over several elements]..... This is a 3 type of product. This one is gas, this one is liquid, this one is mass [meaning solid]… I am not very sure about this one … but I guess there should be a formula to enter a formula of a chemistry product [pointing "*Formula*" field]…

User 05: [click "*Balance*" tab]. It is not immediately apparent how I should input my equation [click blue display field, which shows results for balanced equation]. There is no template or example on how it should be. But I see… a number of buttons that my help me when I put my formulas. Like balance equations, combustion products reaction, acid and base reactions. They all make sense but it is not clear how I put my equation in… oh... There is an "*Examples*" button. That will be good to press. [Click "*Examples*" button]… hmmm… and it tells me it is a reaction that is not really needed to be balanced. It is just writing it out. . So it is not super exciting… I press the balance equation button [click "*Balance Equation*" button] does some?

It does some. Hmm. I was wrong in the first place. It does a matrix algebra and finds the coefficients for me and puts them in to the box where is the on the left side of box of reactants and products. Not labeled but I can assume reactants are on the top and products are on the bottom. It puts the coefficients on the front of the reactants and products on left hand side that makes sense. [Click and scroll in big white display field], it shows echelon equations here. Probably don't mean anything to most people. I will go on.

On the other hand, users also expect *StoiCalc* to give a very direct, intuitive way for a starting point. They also expect *StoiCalc* to provide an interface design that leads

them throughout the process, like a step-by-step walk through without a need for consulting the help pages:

> **User 01:** I just think that, some of the functions in this program I haven't done in couple of years so it definitely helps to remind me how to do that kind of problems. I wasn't like sitting and saying "Oh mine, what will I do, what I will do?" It helped me to walk throughout the process so that is probably how it helped me think….
>
> Definitely if you would stick in the problem, it will help you through out the way of problems, especially if you are having the web manual. [Because there is no embedded inner step-by-step walk through function for *StoiCalc*, they need help files]. If you have just pen and paper and you don't know what do the in the next steps, it tells you what you are supposed to do.

In order to make an intuitive interface design, leading users' minds toward realizing and identifying the starting point becomes very important. Poor starting points in *StoiCalc* may cause user confusion and can mislead the rest of the user's actions:

> **User 03:** [Answering interview 3.1, question 14] I think, the software could be improved by making friendlier. Because you don't know exactly where to enter things, in some functions like "*Balance*" the procedure is shown but in the "*Chemical Reactions*" the procedure is not shown. Maybe for each step procedure could be shown in some big boxes that could make people easier to understand.

User 04: [at "*Solutions*" tab, reading helps but started from wrong step of the help file]

Like the first problem, we need to click "*find MM, REM*"

[Click "*find MM, REM*" button] [Nothing happens]. No, no not this one.

[Go back to help, read again]… it should be click the "*Balance Equation*".

Researcher: Why did you click the "*find MM, REM*" button?

User 04: I just read the wrong step

[Note: Still needs numbers and order in help page].

Researcher: Why do you confuse the steps?

User 04: After I enter formula, I just try that button [click "*find MM, REM*" button] but it didn't show anything so that is not the right way.

User 04: I will just click "*Balance Equation*" [click "*Balance Equation*" button], it will show the right balanced chemical equation, then. [Click "*find MM, REM*" button]. Ok this is right,

Researcher: [at "*Solutions*" tab, user clicked to "*Display Recipe*" button before clicking "*Find*" button to calculate the volume which is a required step before displaying recipe] So What happened when you clicked "*Display recipe*" ?

User 05: Clicked "*Display Recipe*", nothing happened. I need to be [silence]

Researcher: Is that what you expected to happen?

User 05: No.

Researcher: Why?

User 05: [silence]

Researcher: What were you expecting when you click "*Display recipe*" button?

User 05: I guess I was hoping to see [quiet] the mass I should use of KCl prepare the solution. Umm. [Click] .Oh!!

Researcher: So what happened?

User 05: Ok. I played with the units of the mass output. I clicked the "*Find Mass*" in the as a drop down "*find mass, find volume. find concentration*." Go in there. And select "*Find Mass*" [item in the list] first and now I hope I will be able to hit "*Display Recipe*" and it will give me a recipe here. And it did. I guess I wasn't getting the spit out the mass of KCl I should use. That was a bit confusing having to go in to drop down to get it to do calculation I have figured I have to push a button to get it to do calculation but it did display the recipe tells me the mass of KCl that I found up above.

The *StoiCalc* user interface may have some problems directing users in problem solving steps, especially when identifying where they need to have their inputs and in which order they need to press buttons to use the several functions. The layout designs on screens in *StoiCalc* make it possible to see where to input first (or not). Users expected to make inputs into the very first input fields given in the layout:

User 01: I will switch to molar mass [Click "*Molar Mass*" tab]. [Click big white display field] I am going to type in the formula into where it says enter formula [typing formula]

Researcher: You have just clicked the big white box instead of enter formula box. Why?

User 01: When I came to the screen I guess my attention went straight to that, than I noticed where it said "*Enter the formula*". I don't know, maybe it is further to the left that is why I clicked here first versus to top one. When I was using the program first because there were solutions [meaning the yellow display

> fields]. If it would be here [showing the right top area], I would click here initially, first.

Moreover, the affordance and availability of objects on the screen directed users to estimate the necessary steps. For example, in the "Reactions" tab, users easily understood that they need to fill out the table on the screen by just looking it is affordance:

> **User 01:** I think part of it is yeah I have to fill the table. I have the information so it is not like I mean somebody to help me figure out that information. I just need them to figure out what I don't have and so … yeah Umm. You know if I. The equation wasn't balanced. umm I wouldn't know of, I would have definitely went to "*Balanced Equation*" [button] first to put in reactants and products, but since I had a balanced equation I guess I didn't think that I would need to leave off the coefficients, have it balanced it, and bring my coefficients in and umm….

Also, as mentioned before, permitting users to make inputs in output fields causes the interface to be even more complicated; it even can lead *StoiCalc* to crash:

> **Researcher:** Without entering (or thinking) any question (or formula) can you explain me what do you see in that screen?
> **User 04:** I think this one should be bigger [meaning the "*Enter Formula*" field]. Because when people use this software they may try entering things from here [showing and clicking inside the big white display field]… Because this is so big and I can just start typing, if like words [clicks "*Find Molar Mass*" button]...

Than it is just mass up [error, StoiCalc crashed]...It really doesn't work... So you should say people that you need to enter formula here [showing "*Enter Formula*" field].

User 01: I thought, like in some parts like balance the places where the answer is displayed, I thought these parts are for entry because it comes first in top or were I need to enter in are more to the left, like in "*Balance*" [tab]. Those are just few things I had a little bit confusing. "*Chemical Reaction*" [tab], I would say is the most difficult portion of the program but I found an approach for how I supposed to use it. "*Conversions*" [tab] are just very frustrating. I wasn't able to convert form grams to milligrams so that wasn't very user friendly than what I would like. Because I would think you could have a dropdown menu here [meaning "*Grams*" title in "*Conversions*" tab] for the weight, let's say "I want to go form grams to milligrams". That was not possible. The options in the "*Conversions*" [tab] are not very user friendly.

User 03: …it should be some emphasis for that square [meaning green "*Reactants*" input fields in "*Balance*" tab] that may help people to understand where to input. Maybe people can think you can input here and here [showing small pink display field for coefficients and first and big pink input field next to it]. They may not know what that is…

Users expected to have an interface that matched their natural way of engaging with other cognitive artifacts. For example, some users found that the elements on the screen should be from left-to-right, which is easier to attend and read:

Researcher: What do you think about the headings of lines of table?

User 05: Might be more useful on the left, but I didn't look over there immediately. I only saw them there after I got work from left to right through the table. Then I saw the reactants and products label there. And products are difficult to read, it is in the green over white. I didn't see there unit l I work throughout a little bit.

User 0: [at "*Balancing Equations*" tab] … But I guess it is a little bit confusing because the "*Balance Equation*" button is lower left part of the screen where as it is shown on the top at the upper most part of screen that we worked. From the user's point of view, it would be easier to have that "*Balance Equation*" button near to the display where we work with balanced equation, which is on the top. Rest of is to find molar mass and reaction equivalent masses and amount of products used. There is also a "*Combustion [Products]"* button that we have used…

Actually what occurs to me, as long as we read from left to right it will better to put reactants and products titles to right? That is just a personal preferences I guess.

…In this particular "*Chemical Reactions*" part, there are two points it will be nice to have; the "*Balance Equation*" button should be near where the screen displays the balanced equation. So my eyes don't jump form top of the screen to the very bottom. Also to have reactants and products written on the left hand side simply because we used to read left to right.

In *StoiCalc*, the choice of labeling on the buttons also led user's minds and their decisions. For example, selecting a key word that is unlike the function it is representing may confuse users:

> **User 05:** Click "*Combustion Products*" [click "*Combustion Products*" button] and it gives me an O2, on the reactants side I guess. But I am not sure, it is not exactly labeled. Click on the "Formulas" button to just to see what this tab is about [click" *Formula*" Tab]. [Read tool tip] Looks like it finds theoretical molar masses from molar formula at the top and then empirical molar mass at the bottom. No examples for input really. You have to know what you are looking for I suppose.
>
> **Researcher:** What do you think about "*Combustion Products*" button?
>
> **User 05:** It is a bit misleading. It is labeled as "*Combustion Products*" and it also puts in a combustion reactant as well. But I guess it wouldn't be completely obvious to me without seeing the help page. Yeah, I learned about the "*Combustion Products*" button from the help page.

> **Researcher:** Can you explain more about the "*Combustion Products*" button?
>
> **User 05:** It says "*Combustion Products*" but it puts O2 in the reactants, which is a necessary reactant. But the button says "*Combustion Products*". That is a bit misleading.

> **Researcher:** To enter a new formula you use the "*delete key*" at the keyboard. Do you think there is another option?

> **User 03:** Maybe clear button [showing "*Erase All*" button]... I see... all things disappeared. All the calculation charts and numbers disappeared. But I am not quite comfortable with this button because the color is different than the "*Find Molar Mass*" button. So I would not risk clicking this button because something disastrous might happen that I may need for the calculation. Maybe there should be a button just for clear the formula. So that is my expectation for that button. Because this type of "*[Erase] All*" button I can not want to click
> **User 03:** So I'll click to "*Erase All*" potentially disruptive button here clears everything up and I enter NaNO3 up in the formula box.

In addition to design of interaction steps in schemes, keeping the visual layout as simple as possible may also make users less confused and reduce their memory loads. Users recommend that keeping screens simple and making the frequently used buttons more visible may be useful:

> **User 04:** For this one ["*Balance*" tab] there are too many buttons. Maybe those buttons maybe useful for other types of problems, like next coming problems. Most of the simple problems I just should use this button ["*Balance Equation*" button]…Maybe you can make this button bigger or clearer for the user to press.

> **User 0:** "*Balance*" is also nice. I just kind of wonder about the way to input, because there are lots of input fields in the balance, but probably I would try them later.

Some of the functions connected to interface elements are not directly visible to the users. These hidden functions may confuse users to find their way in *StoiCalc*. For example, in the pure solutes part of the "Solutions" tab, a participant didn't realize the functions that were found in a drop-down menu. Because all the available items to run calculations were "hiding" in the drop-down menu, this user tended to skip them:

> **User 03:** … I'll check my manual… I see that is a display box, not an enter box. So the find the "*Mass*" option is a clickable button, not menu like units.
>
> **Researcher:** Can you explain to me more about the "*Find Mass Menu*" ? What makes you confused?
>
> **User 05:** Mmm! Well I guess I didn't think to having to go into a menu for a calculation to be done. I thought I would maybe… you know. If it's looking to "*Find The Mass*" maybe I click find this variable and then click a button find or maybe that be worked in the whole calculation display recipe. Because it is certainly could calculate all of that just clicking the "*Display Recipe*" button. Umm. I just had to get it to output that mass so I could see it before I found the recipe first. Umm …. So if it was something if the solute was a liquid or something …? I use a volume, I suppose. That is what this would be used for. Umm! Just a little confused in this case I guess.
>
> **Researcher:** So you prefer buttons or something like that?
>
> **User 05:** Yeah mmm yeah! It's just not the way I am used to getting something to do calculations. I usually don't think I have to go into a drop down to do the calculation. I usually do something by clicking the button to get a calculation done.

Researcher: Ok. So did you find what you expected to see?

User 05: Yeah. Once I got everything input correctly. Once I figured how to use to "*Mass*" input at the bottom of the pure solutes…

Researcher: Why did you click "*Display Recipe*" first?

User 02: Because, I thought that when I click "*Display Recipe*" it will get me both this field ["*Mass*" display field] and this field ["*Display Recipe*" display field].

Researcher: Expected to see?

User 02: When I pushed the "*Display Recipe*" this is [meaning recipe] what I expected to see, I also expected to see the mass.

I recognize this is a button now "[*Find Mass*" menu] and not a just a menu.

User 02: I didn't recognize this menu as the button ["*Mass*" button] to fill this information in but this was the button ["*Display Recipe*" button] that solves the all unknowns.

Unlike hidden options, there are some options that repeat on the screen and may create potential confusion for users. For example, in the "Solutions" tab, there is more than one option to select milliliter and liter. One option is the shorter versions like mL and L and the others are whole spelled out words for these units:

User 05: I go to do drop down menu ["*Unit*" menu] and change it to milliliter. It has 2-milliliter options -- mL and milliliter spelled out.

Researcher: Which one will you use?

User 05: I am used to seeing mL. I don't think it should make a difference. [Change ml, milliliter and find volume, and try couple of times to see the difference]. And it doesn't.
I changed from the mL to millilitre, I found the dilute volume. It remained same.
Researcher: Why do you think there are two ways?
User 05: Two ways to display it I think, I guess I am not sure. It gave me the same result. It is just redundant.

In *StoiCalc* design, some of the interactions were kept as mystery to the users. For example, some tabs of *StoiCalc* included an "Import Equation" button. This import function of *StoiCalc* was not clearly explained in *StoiCalc* itself or in the online help. Participants tried this option, but they couldn't figure out what was happening. Using the import function didn't make any major changes in their work progress, however; it just remained a "mystery":

User 0: What is this? I wonder what import is equation is [click "*Import Eq*." button]… Choose a target feature. Ohh… so I see this is curious what I understand is probably I can import equation that I have here to two or three targets. I would expect "*Dimensional Analysis*" button [in the "*Import*" message display] comes before "*Chemical Reactions*" because that is the order that is there in the top menu ["*Tab Bar*"]… this is reversed here… I would cancel it [click "*Cancel*" button]…

Researcher: I remember you have clicked the "*Import Equation*" button. What do you think that button does?

User 04: I first I enter the whole equation here [blue display field], and I think there is some button choice here [meaning the message box coming with options for "*Balance*", "*Dimensional Analysis*".] and then I clicked the "*Balance*". But it was not the right way,

Researcher: So why did you click balance in that massage box?

User 04: Cause I just want to check if the equation is right. I think the computer will balance the chemical equation if it is not right.

Because there was no clear explanation of what the "*Import Equation*" button does, and there was no visible clue for what is happening when users click on "*Import Equation*" button, some of the users even thought that the import equation is displaying some data external to *StoiCalc* :

User 01: So there is a blue box that pups up here. So you can import reactions in it. I will try that feature… [User clicks "*Import Equation*" button…. "*Message Box*" appears]…mmm. Mmm… [Clicks "*Balance*" button in the "*Message Box*", nothing happens]. Import equations…. Would be if there were an equation somewhere like in Internet or in a word document or something it will bring in that enter here.

[Clicks "*Import Equation***"** button one more time and clicks "*Dimensional Analysis*" button, nothing happens]…mmm… [Clicks "*Import Equation*"button one more time and clicks "*Yields*" button on the message box, nothing happens]….. [Note: Confused]….You know what…. I am just guessing there is just no equation to import. I don't know what that function does... when I clicked

on… mm… [Note: User tries to remember the buttons in the "*Message Box*". So he clicks the "*Import Equation*" button one more time]…

User 03: Import equations. [Reads tool tip]. What is another feature? Maybe they are coming from any other buttons in the software.

Moreover, some of the interactions without obvious logic made frustrated users. For example, in the "Solutions" tab, there is a checking mechanism to see user's intentions to erase fields before entering any data. When a user clicks onto a field to enter data, *StoiCalc* asks to check if they are really wanted to erase these fields. This mechanism frustrated users because they believed it didn't work logically:

User 01: I want to enter 400 mL but it says "*Erase fields*" ["*Erase Field*s" message appears, clicks "*Yes*"]. It is not allowing me to do anything. ["*Erase Field*s" message appears, clicks "*Yes*" button]. So I am not really sure why that is. [Clicks "*Find MM*" button.]; ["*Erase Field*s" message appears, clicks "*Yes*" button]. All right well. I'll look at "*Conversions*" [clicks "*Conversions*" tab]. [Gives up and switches to a different function].

Ok. I don't know now why… I just figured I have entered something unknown but I click that "*Yes*" [button], I figured it will erase something but it didn't. I am not sure why that is. May be I wasn't clicking on the right spot may be I was not … so don't know.

Researcher: What do you think about the "*Erase Field*s" message; what happened there?

User 01: I would have expected that I had entered something in wrong or this wasn't the right function of the program to be using. Because I thought that I was clicking in the volume box but maybe I was clicking onto this item [meaning menu next to it] that I am not exactly sure why when I was clicking on it didn't work. Then it said, "Do you want to erase all the fields"; then I said 'yes'. And then it didn't, it didn't erase the formula or the molar mass displayed. So I didn't make sure why it didn't do that if that was it was asking, "Do I want to do?" I just thought that I would be starting over from very beginning.

Researcher: So you thought you made an error or something?

User 01: Yeah.

Researcher: So did it change your approach to the problem?

User 01: Yeah, because when I got it in couple times than I am like, Ok I may be in the wrong function of the program so I was just went to conversations function but that wasn't really what I needed, so that I went back to that screen ["*Solutions*" tab], I clicked there again and I was able to do it. So I don't know why that was.

Finally, not all the interface elements were clear to users. When interface elements were complicated to understand, users felt they don't know how to use these functions. In *StoiCalc*, some of the participants tried to understand some interface elements to find their ways in the *StoiCalc* but they ended up thinking that they don't know how to use it and did not use the function, especially in free exploration tasks:

User 0: [while performing free exploration at task 02] I see what "*Conversions*" have [click "*Conversions*" tab]…. This looks fairly complicated but more user friendly than "*Chemical Reactions*" and "*Dimensional Analysis*".

These have different units. Not sure where these values coming from… Let's try H.

[Click "*Find Mass Mole*s" button]… No… I wonder where it starts. Lets start O.

[Click "*Find Mass Mole*s" button]… nothing happening.

Hey wow. There is something else. [Click "*Find Mass Mole*s" button], I can find the molar mass of O that is 16, which is correct. Let's try H, [click "*Find Mass Mole*s" button], that is 1.

Ok, I figured out something that works. But I am not sure about how the rest work. Lets if I choose an H STP [click "*Choose STP*" button]… That is good these make sense volume… not sure… find volume

I think I probably need to learn more about this software before I can do anything. I am just going to skip this and do the last sections [tabs] [click "*Yields*" tab] …

User 05: I went to the "*Yields*" tab. It looks like we can import equations again and input equations [showing the blue display field], like we did previously. We can add products and reactants but not immediately clear how everything should be. Nothing is really labeled on the right hand side [showing the red framed items].

Good and Bad Intentions of StoiCalc: What happens when it Directs Users.

Cognitive artifacts may lead users' minds intentionally or unintentionally. *StoiCalc* interface design can lead users' mind in a direction where they can successfully accomplish the tasks and get results easily and without difficulty. At the same time, the user interface can lead the mind in a direction where there can be difficulties and confusion. The problem and confusion may also lead to unsuccessful operations or to obtain incorrect results.

What happens when *StoiCalc* successfully or unsuccessfully directs users? How can the users' minds be directed as the result of a good or poor design in *StoiCalc*? This section analyzes these questions.

Sometimes *StoiCalc* users have difficulties that make tasks difficult and/or even impossible. These design issues may have very different roots. What happens and how users think when there is a design issue is also very important to understand how *StoiCalc* leads the mind.

The very first common reaction of users in poor design is to find tasks too difficult to accomplish, even though they understand or know how to do these tasks without *StoiCalc*. The problems didn't derive from lack of knowledge; they were derived as the result of not being able to accomplish them easily with *StoiCalc*.

> **User 03:** Before I look into the help file I don't know how to input the formula for the elements. I used lower case; the result was kind of weird. I did not know what is happening, what was the result. I tried to use upper case of the formula; the result seems kind of familiar to me based on my chemical experience. I can double check and I can see how atoms in the formula, and how the mass in each

> atoms. If the procedure is verified and consonant to what I expected, I can say that result is consistent with my experience and right.

For example, after experiencing the interfaces of different *StoiCalc* functions, some functions were thought to be confusing and got users "lost" in the program. This led them to think the design of interface was confusing for simple tasks and that the *StoiCalc* application makes simple calculations complicated.

> **User 02: "***Yields*" seems to me such part of chemistry with simple calculations but it is complicated application.

In these situations, a user may become frustrated. S/he might feel a need to seek extra help. Sometimes users simply give up performing the task. For example, users described they felt and needed to seek further help in order to understand the interface operations:

> **User 0:** "… I couldn't figure our most of them. The only two things I could use intuitively were "*Molar Mass*" and "*Balance*" [tabs]. I was able to figure these out, but the rest of them came out with the understanding that I need to be thought or someone have to coach me through the software. Nothing new from a lot of software but I was expecting something like help for each options in on the top that thing like a menu bar. "*Balance*" has an example which is great, because when you click the example you would have a o through on your on. "*Molar Mass*" was relatively easy so I could figure it but rest of it I was needed extra help. For me it was a fairly frustrating experience."

In the "*Solutions*" tab of *StoiCalc*, there is an "erase fields" messages warning to users that *StoiCalc* will erase the fields whenever they enter data into the fields. However, without an exception of selection "Yes" or "No" option in this message, it keeps coming up. That leaded some confusion and frustration for some of the participants:

> **User 01:** [at "*Solutions*" tab] I entered the formula into the first box and clicked the "*Find Molar Mass*", and it appeared in molar mass field, and this "*Erase Field*s" box popped up which I was not sure why that was happening because all the fields were already erased…
>
> **User 02:** [at "*Solutions*" tab] Next step should be putting KCl here, [start typing the formula].
> ["*Erase Field*s" message pops up]. No. [Click "*No*"]. [Click "*Volume*" input field, "*Erase Field*s" message pop up]. Yes [click "*Yes*"]. Click "*Volume*" input field , "*Erase Field*s" message pop up]. [Click "*No*"]. Ok. "*Find Molar Mass*" [click "*Find Molar Mass*" button].
> ["*Erase Field*s" message pops up]. Yes. [Click "*Yes*"]. I don't see anything erasing in these fields. [Click "*Display Recipe*" field]. Ok, Sooo.
> ….
> **User 02:** I still don't know what it means because when I clicked here ["*Volume*" input field] it will come up with the clear all the fields. Then after coming from the instructions [meaning help page] it didn't come in, it no longer did it. But I don't recognize what I did differently or if I just clear all fields before going instructions or help.

….

[Enter formula]. I start pushing find the molar mass. Ok.

Erase other fields [”*Erase Field*s” message pop up]. Mmm... .

Researcher: So what do you think it does?

User 02: I have no idea.

User 02: I am going to click the yes, because I clicked the no before.

Actually I clicked them both, but … Ok. Maybe it is just something that comes up for these 3 [“*Volume*”, “*Concentration*”, and” *Mass*” input fields]. You may have data in there already. I am not sure. I am going to click yes, and try to write down my volume here. [Click “*Yes*”].

Ok. It doesn’t. Thank God.

User 04: I think this would be the same. Just enter the formula of this product.

[Enter formula into “*Formula*” field; click “*Find MM*” button]

[“*Erase Field*s” message pops up, click “*Yes*”].

[“*Erase Field*s” message pops up, click “*Yes*”].

[“*Erase Field*s” message pops up, click “*Yes*”].

User 04: How to erase that!!!

[“*Erase Field*s” message pops up, click “*No*”].

I already erased them

[“*Erase Field*s” message pops up, click “*No*”].

[“*Erase Field*s” message pops up, click “*No*”].

User 04: I think this would be the molar mass of NaNO3, do I need to erase it?

[Erased NaNO3]… no…

Ok. Maybe it is not changed [type KCl, click “*Find MM*” button]

[“*Erase Field*s” message pops up, click” *No*”].

User 04: No, it is changing, so this value is correct. [Type NaNO3, click "*Find MM*" button]. ["*Erase Field*s" message pops up, click "*No*"].

Researcher: What do you think about this message?

User 04:I think this is like the button "*Erase All*" [showing the "*Erase All*", button on the "*Molar Mass*" tab], it erase all these boxes. [Confused.]

User 1 and User 2 describe how they think about the easy of operating in "Solutions" functions of *StoiCalc*, and they utter their frustrations. Also, user 2 describes how it affects his confidence:

User 01: Everything was relatively easy. Except that "*Erase Field*s" [message]. I can't copy not using my lane. I didn't know why it was doing it. I feel like I was doing something wrong. It is just more than distraction then anything. It didn't alter what I was doing but I just don't like why it keep doing it. It is annoying a little bit.

User 02: (I think "*Solutions*" tab is) more difficult than "*Molar Mass*" tab.

Researcher: Why do you think it is more difficult?

User 02: It has a lot more options. More overwhelming when you first open the application for solutions. After looking to the help page and overcoming that crazy erase all fields window it is pretty easy to use.

Researcher: Do you think that pop up message change your way of approaching to solve the problem.

User 02: It changed confidence… I thought, "Oh, crap, I am going to consult the instructions. But the instructions basically told me I thought I already have

known, so I came back it worked. I don't know. The window obviously didn't change because I went to the instructions and came back and I thought I handle it. I still quite not understand what is about in the program. I don't see [go back to help and scroll] anything in this help page that tells me about this window coming up and asks me to clear all fields… I don't know. I think maybe it refers to the other fields in the program [clicking tabs and see the other tools]… I don't see any.

Users may change their actions when they encounter some difficulties and frustrations because of bad design. The following examples demonstrate that, *StoiCalc* poor design can lead users to change their minds:

User 02: I know the concentration of stock solution, which is here. [Click "*Con.Stock Solution*" field]. ["*Erase Field*s" message pop ups]… oh. No. [Click "*No*"]. Ok I am going to erase all here. [Click "*Erases All*" button]

Researcher: Why do you think you need to erase everything?

User 02: I don't think I should, the "*Erase Field*s" message boxes came again and when I pushed off yes I expected these fields to disappear but they didn't. So I just going to play safe and click "*Erase All*" and start all fresh. So I am not a fan of that message.

User 05: Every time I click "*Find Molar Mass*" it asks me if I want to erase other fields.

Researcher: So what do think about that message box?

User 05: If you are doing a number of these calculations it seems like a bit useful if you don't want to. Well yeah. If you are just going to be running through a number of these, then just being able to put in the formula and click "*Find Molar Mass*" then having that clear out seems you are cutting out step of clicking the erase all button I guess…

In another case, again in the "Solutions" tab, when users select and/or change their units of volume from the drop-down menus, the input they made is deleted by *StoiCalc* without any warning or confirmation. This behavior of *StoiCalc* is generally unexpected by the users and they thought that was a poor application design:

User 0: [at "*Solutions*" tab, types data into fields.]… I have to change it to liter. …. [Change L in units, program delete data in volume]… upss.
That is not good. I did not expect the number I type will disappear once I changed the unit.

User 01: [at "*Solutions*" tab]. I am going to put the volume in mL [click "*unit*" menu select mL]. And the for the unit concentration [click " *Concentration*" field, "*Erase Field*s" message pop ups]. I still don't understand why these "*Erase Field*s" boxes are popping up. So I click "*No*", I don't want to [click "*No*"].
My concentration will be 0.850 molar [type in "*Concentration*" field] and the volume would be 3.00 liters [type 3.00 in "*Volume*" field] in liters [click "*Volume Unit* " menu, select "*L*"]. So when I changed the volume it erased the volume I have entered, so I am going to re-enter it [type 3.00 in "*Volume*" field].
Researcher: Is that what you expected?

User 01: It was unexpected. I think I really could change the units that having not deleting something in the volume field. I don't know why it erased that.

Finally, some options are redundant in the interface without doing something different. This redundancy led to some confusion for users. In the "Solutions" tab of *StoiCalc*, users found that there is confusion because of presences of double expressions of liter and milliliter with short versions and long versions together in the unit selection list, when they are asked to explain the reason of redundancy:

Researcher: … Why do you think there is mL and milliliters?

User 01: Maybe, it is because if it is written out kids will figure out what they will be using. I am not really sure.

Researcher: Do you think that makes a difference?

User 01: I am not really sure, let's find out [change to unit mL to milliliters to try and click "*Find*" menu]. No it doesn't change it any. I guess that would potentially confuse me. I mean I didn't notice that one when I clicked drop down menu earlier. But I can see that could be really confusing to students. It is not something I expected.

Researcher: can you explain what you see in the unit menus?

User 02: A lot of choice for units for volume. I don't know the difference between this to [mL and milliliter]. [Read menu aloud]… This might just. [Click "*liter*" option].

…

Researcher: Why there are L and mL?

User 02: mmm…. I change to it L to word L, and click display, I expected to sees the written word there in the recipe. Units are the same but the display recipe changes.

Researcher: Which one will you use if the question asks L? Wording or short version?

User 02: Short version.

Researcher: Did you have a doubt to choosing?

User 02: If these were missing (L and mL) I would blink to see these [wording] instead but it wouldn't make me hesitant to choose them if I knew I was in liters. Given the choice I would choose L and mL.

Researcher: Is the result expected to see?

User 02: Yes.

Researcher: What is the difference between L and liter?

User 03: mmm... I don't know. Maybe L is simplified liter or liter is for somebody who is unfamiliar with this unit. Maybe Americans use gallons for volume. But I think there is no need for these two units because they exactly result in same form. They are exactly same. I dent know why they use liter and a capital L. I don't know.

Researcher: If the question were asking milliliter instead of liter for the volume what would you do?

User 04: [change it to "*mL*"] I will change it here.

Researcher: Would you choose Ml or milliliter.

User 04: I think mL. There are two. I think mL is the true one. I think I am not sure about the meaning of milliliter.

Researcher: So do you think it is the same thing?

User 04: I think this is the same; I am confused about why they are re-used.

The presence of poorly designed items is not the only cause of user confusion and/or difficulties. Functions that are not present in the artifact design can also lead users' minds. For example, in *StoiCalc* "Chemical Reactions" tab, input fields are labeled as "Mass g after" and "Mass g before". This labeling may direct users to think that these input fields are expecting data in the form of gram unit therefore users may needed to make a conversations to format their data in gram form. However, when they needed to have a function to make these conversations, *StoiCalc* does not provide a clear and automatic way. A possibility of having poor design in labeling and lack of functionality leading users' mind emerged in task 3.1:

Researcher: The column says "*Mass G After*"; what do you think about that?

User04: I think, although "*Mass G After*" is g [gram]; if we use both of them in mg we can us in the same way. I assume both of them are milligram in this case, both of the left side and the right side of the equations is same so that is not a matter.

Researcher: If you don't know how the equation works, what would you do?

User 04: I would put 0.0071 in the "*Mass G Before*". Now this is in gram. And click "*Mass Products*" and it gives it 0.0259 gram. Maybe this is more accurate.

Researcher: What do you think about the labels in the columns for "*Mass G Before*" and "*Mass G After*" *?*

User 04: mmm. A little bit confusing but I think everyone can do that, they can just change the units.

User 05: I don't know. There is no way to change these units for mass before and after. So I just have to convert it in my head apparently.

Researcher: Do you think this confuses you?

User 05: I am comfortable converting grams to milligrams, I think.

That is milligram in the result because I had input the mass g as gram. So the output is gram.

It will be handy if you could change the unit label here like you could in the solutions tab we were using. There has been ability to change the units through the software. It is not changing on this one ["*Chemical Reactions*" tab].

Researcher: Do you think students can just jump to gram and just write 7.71?

User 05: Probably, because that is how it is written on the worksheet and they might not attend this format to be inputted in the program. They may use as it is.

Researcher: Try to use 7.71 in "*Mass G Before*" ?

User 05: I guess it wouldn't make any difference if you using same units there. Does it? [Trying...]

User 05: Yes, I was adding an extra conversion steps that I wasn't not. If you go from grams to gram the ratio of grams to grams is the same as ratio milligrams to milligrams.

Researcher: Do you think this mismatching title for gram makes for a little bit of confusion?

User 05: I was getting little bit confused back there. If you know the ratios should be the same between this grams products and grams reactants and milligrams. It will be nice if you can change the units, it will be more expressive. A little bit of confusion.

User 03: Mass before reaction is the the amount of reactant provided.

But I don't know how to put the milligram in that software. Milligram. Ok I will check the manual again. Ok. Maybe I can use the scientific notation… I can put 7.71 E -3 [click in "Mass g before" field, enter 7.71 E-3]…

[Click "*Mass Products*" button], check that.

Ok. 0.259 that is the mass in milligram.

Researcher: Does it make you confused?

User 03: Because it says mass gram before, it is already determined unit that is gram. There is no milligram, that made me think. Based on my chemistry knowledge-converting gram to milligram-there is no point. There is no connection between the units and the answer. The only thing import is the number you give here.

If one gram produced two gram O2, I can say 1 milligram produced 2 milligram O2. That is about proportional coefficients, they are same. Converting is a redundant process.

Researcher: What do you think about the title "*Mass G Before*" and *"Mass G After*"?

User 05: I don't … I have conflicted feelings about grams in the title. One can be, it can encourage kids to change values to grams before entering data. Units are everywhere you should have all the units for the numbers on your report but it is also not necessary if the students understand whatever units they use here will be given in the calculation in the same units. It doesn't bother me if there is gram there. I realized I needed to worry about it.

I think, in general, kids would convert this number to 7.71 E - 03 [trying with this number]. Yeah, they will get 0.0259.

> Then I will take this number in grams to convert in milligrams, I need to multiply it with 1000. I will get 25.9. In this case because of significant figures, it will require kids to take extra two-steps. They will either realize they needn't use this two-steps or got this was in grams and they just enter it as data.

Moreover, the presence of the "Dimensional Analysis" tab and "Conversion" tab may lead users to think that these kinds of unit conversion could be done directly in these tabs:

> **User 02:** Now, I realize it is in milligrams [type 7.71 in "*Mass G Before*" field] but if I assume mg, instead of grams. Yeah, it says milligrams for benzene but I mean, I could go to dimensional analysis and say it is 7.71 times ten to the negative third grams and I will get an answer down here.

One user attempted to use the "Conversions" tab to perform a milligram to gram conversion, but it failed. Moreover, as in the above case, that user faced the same kinds of difficulties in understanding *StoiCalc*:

> **User 01:** I need to. Mass in milligrams. Then the convert button. So I guess it was not clear to me if I could have left it in milligrams it would have given me my answer in milligrams or if I needed to change it because [clicking to "*Conversions*" tab]…. [Clicking and silence]
> I can only find that in gram. So I had a convergence and I wanted to go grams to milligrams but I guess that's not in the option mmm because when I click "*Mass Weight*" it says find gram or find mass weight so. I mean.

Researcher: What do you expect to see?

User 01: It is not what I have expected to see. What I would have expected to see I could have converted any kind of weight to different kind of weight. Umm.

Researcher: So do you think titles are a little bit misleading?

User 01: Yeah. Because. So basically you can only go from all these different grams, kilograms, milligrams, micrograms, nanograms, pound, once, stone, ton and tonne to grams you can't really convert from one to so I convert from grams into milligrams I would have to convert from nanograms to grams. But I just want to try and see If I can just put in to milligrams and see if it would -- I mean. My guess is I thought it would just carry things through. I don't know; I am just curious. I am going to try that so 7.71. It says 26.1 when I when I am converted it to milligrams it was .0259 so and I mean when you multiply that by 1000 it would be 25.9 grams so this is not as accurate for sure. Because it is saying that it would end up being 26.1 grams.

Researcher: So what happened?

User 01: When you don't change it to milligrams your answer is not as accurate as it should be. So and I mean I can convert from milligrams to grams basically in my head but I guess I though we are going to need to utilize the program that's why I am using the convergence mode. And it wasn't doing to convergence for me as far as [expected]? Student I can see that like they wouldn't know the difference. I think it would be helpful if you could maybe choose what you're mass before if it wasn't in grams, in milligrams and kilograms whatever so then you know it was. You didn't how to question what you should or shouldn't enter. And then in convergence screen it would be helpful to be able to do convergence between more than just one unit grams but like between grams and milligrams and nanograms and milligrams and all that .

Researcher: So do you think it is creating confusion?

User 01: Yeah. A little bit of confusion but more just kind a like it wasn't doing what I expected in the convergence screen for sure. With you only being able to do in grams it is a bit confusing and its kind a like. You know when I converted my grams to milligrams it gave me or my milligrams to grams then it gave me my answer in grams in a decimal and then I wasn't able to convert that back to milligrams. So and then obviously if you just try to enter in milligrams and just say that it would be umm. You know the 26.06? It would give you. If you would have 7.71 entered in there and it would just give you the answer saying as what it would be. It is not very accurate. I mean its close but it is not 100% accurate

Finally, users may want to modify the results given in the *StoiCalc*. Lack of functionality to modify given results may lead users to think to find another way to make and/or force *StoiCalc* to calculate. For example, in *StoiCalc* the "Molar Mass" tab calculates and displays a molar mass for a given formula. When there is a need for calculating formula mass for more than one mole, there is no option provided in *StoiCalc*. This lack of functionality leaded some participants to find a method to make *StoiCalc* calculate more than a mole:

User 02: I wonder if it calculates more than one mole.

[Click to yellow display fields, click the one shows for 1 mole and highligted, type 2, click find "*Molar Mass*"]

[Software gave 1 back]. . Yeah I am not really sure what is the purpose of this [Yellow fields]. I taught perhaps if I changed it 2 moles it would give me, double of this number [showing, yellow display fields]. But it didn't.

Researcher: Can you explain me what happened when you click find the molar mass?

User 02: When clicked the button it computed molar mass, for this formula. And shows you the work and the result.

User 05: … So I can see the ratios are one mole. I can use a calculator to multiply this by two [showing the result at yellow fields]. I wonder if I can get by just putting 2 before the whole formula, if I put parenthesis two find if it would double [type parenthesis and 2 before the formula at formula field]. And it works, too. I put a coefficient of 2 for the compound and find the molar mass of that as I expected. So I get twice of each element of this compound and it make sense, the answer is doubled what it was before.

Researcher: Can you explain the yellow boxes?

User 05: It shows the ratio, ratio shows the grams of the compound for one mole of the compound, but the compound I have input this time was the initial compound wit the parenthesis with the 2 after it.

Researcher: What do you think about that?

User 05: mmm…. I kind of tricking this program, it is not normally it uses this I would imagine but it still works and gives me the double of the ratio I had before of grams to moles.

Expressing yourself to StoiCalc (Input):

We begin to interact with our artifacts as they become "more intelligent." Designers have provided ways of interacting with/within cognitive artifacts by assigning several interaction methods. Artifacts, especially computers, need to "understand" users'

requests by interpreting the user's inputs. On the hand, users also need to understand the artifacts' expressions by interpreting the artifact's outputs. Furthermore, the artifacts' inner states are not visible to the users in many cases, so users have no way of understanding the internal state and process of artifacts. In order to assure good communication and interaction between humans and artifacts, efficient ways of expressing and understanding for both need to be established.

> **User 03:** I think this software is a kind of scientific chemistry software. First you have to enter the computerized format of data. Your entry should be recognized by the computer and the formula should be written in another way [than the traditional formats].

Users need to have a way to tell *StoiCalc*. Interface items such as buttons, menus and fields are the main methods for the user to express his or her instructions to *StoiCalc*. Formatting data for input is fairly easy in *StoiCalc*. Nevertheless, users need to know how to format their expressions to communicate with *StoiCalc* appropriately:

> **Researcher:** Can you explain the big white box, what do you think this is for?
> **User 03:** [reading tool tip]. .. [Thinking]... why this is 14... Why there are no 14 products. … Mmm… [Still thinking]…
> **Researcher:** Do you think there is wrong formula?
> **User 03:** I don't know, I don't know if it is. Ohhhh [surprised]….. Maybe I... maybe I can try the capital one. Maybe it can give some different results….
> Here is the capital … ahhhhh…. So that is it …

Researcher: So what happened?

User 03: Yeah that is for that… Summation of 3 elements, so there are 4 0, 1 S, 2 H... the mass of 4 O, 1 S, 2 H... so that is the total molar mass for this material...

Researcher: Is that what you expected to see?

User 03: Yeah that is right now.

Researcher: So could you explain to me what happened when you click "*Find Molar Mass*" button?

User 03: So I needed to find the molar mass, so there are "*Balance*" [showing the buttons on tab bar], I don't know the formula but it says this acid. When you put in small case, there are 14 H, but I am not sure why it is not lower case. When you put upper case, the atom, it is totally different. Because in capital case, then make sense. This 2 means the quantity of atoms of H. Then makes sense.

Researcher: So this one [with caring the case sensitivity issue] is what you expected to see?

User 03: Yeah, this one . According to my previous chemistry knowledge. But I don't know why the lower case doesn't work . I don't know yet.

There are several *StoiCalc* input rules. Unfortunately, in the *StoiCalc* itself there are no directions directly explaining these rules about formatting users' expressions. On the other hand, the online instruction manual (help pages) gives detailed information about formatting the inputs. Participants learned the rules about formatting their input by reading the very first page of the online manual that is labeled "About":

User 01: "…so it has a table here showing the conventional formula and how you should enter it into software. So…. It shows in the conventional formula

there is a dot but you would use a decimal instead. For more complex molecules, then how would you enter them… Let's see what is down here.
It shows you how to do scientific notation… just pretty standard to enter on a computer. Talks about significant figures. [Scrolling and reading silent]…"

User 02: It shows you how to enter formulas. Hydrates are periods, interesting. Scientific notation, just like the calculator. Significant figures, so it uses significant figures; that's good. Just reading this really quick… [Scroll down, read silent].

Reading instructions in the online manual helped them to recognize that *StoiCalc* accepts formulas and notation in different formats than the ones they generally use by hand (such as subscripts in chemical formulas).

User 03: … [In] this help file, I can see, there is the comparison between conventional formula and computer formula. They are kind of different from conventional formula, which are written in textbooks. There are different writing [formatting] cases for this [*StoiCalc*], you have to write formula differently. If the materials are consisting of two molecules like water, in conventional formula there is a dot between two. But the dot is replaced by a decimal dot when you put it with your keyboard, which is not the same.
There is upper case for the ionized coefficients; if this is upper case you should write some kind of sign into computer.
Scientific notation. Conventional notation number expression changes when you use it in computer to E [exponential]. This is quite understandable. If you use

> Excel files, you know the scientific notation should be written in this way. That makes sense for me.
>
> I think, before I read the manual it was not quite easy to get into that. When I first balanced the equations I used plus in the formula of reactants. Actually the software recognizes that as two reactants. So it is quite easy getting to that software only if you read the manual. Without manual it is not easy, it makes me confused. The format of entering data is not difficult but you have to know about it.

On the other hand, some of the participants noticed that the "About" section in *StoiCalc*, that is directly implemented in *StoiCalc* does not provide the same information. Perhaps the *StoiCalc* "About" section should directly give some brief notice about formatting inputs.

> **User 03:** "*About*" function in the software is quite different form the "*About*" function in the manual. The web page is about how to express yourself in the software. In the software the about function is illustrating all the functions which can be used. So like, what is the function of conversion, what is the function molar mass etc. That is kind of different than web [manual] page. I think online manual is a kind of guidance for you to get into the software. As you can see here, in different functions [showing tabs], it shows how to import your formula or enter your equations to the software. It also shows what you would do in different situations.

Incorrect Expressions and "Hidden Treasures":

Even though there are explanations about how to express oneself to *StoiCalc*, several users struggled in forming acceptable input formats. Either they didn't realize that formatting is explained in online instructional manual or they forgot to format an input in spite of reading the instructions. They also weren't aware that formatting expression would make a big difference in *StoiCalc*.

> **User 01:** So when I clicked the "*Launch Web Instruction"* button on "*About*" tab, a web page came up. And this is an about page… mm. A web manual. It talks about how to enter formulas. Making them case sensitive. It makes I am sure, I am aware of that, and which is good to know cause I think sometimes students wouldn't necessary realize if they did everything lower case or upper case and if it would make a difference.

Expressing exactly according to *StoiCalc* acceptable formats makes a difference in *StoiCalc*' s calculations. The majority of users had difficulties when they formatted their inputs.

> **Researcher:** What do you think about that [How to format excess oxygen]?
> **User 05:** It is an … I don't know. It is not immediately clear that how you should put it in zero if you want to excess O2. But it looks like the program seems Ok with negative masses. I don't know. It gave me the right answer. I don't have a real big problem with it. I just need to know that how to format the excess of a compound .
> **Researcher:** Do you think you need some directions ?

User 05: I think you should have some. Maybe in the help, I didn't look at the help, may be it has some directions how to put in an excess. It would be helpful. Because you have to do the calculations first and it seems like you need to know what excess is. So you do some part of the calculation to know what an excess amount would be.

In formatting variables as numbers, they often skipped rules for using scientific notation. Using appropriate significant figures and notation in scientific calculations made important differences. Many users forgot or didn't attend to the ability of *StoiCalc* to calculate using significant figures rules.

Researcher: Do you think it is going to make any change if you use significant numbers in that program?

User 05: I wouldn't anticipate that makes a change. It might. It may give me more decimal places in the volume of stock solutions. Let's try that [entering numbers using sig. fig.] . It may give me extra decimal places in the volume of stock solution. [Re-calculate with significant figures]…

So. It gives me a very different answer. It gives me 850 …

Researcher: Is that what you expected to see?

User 05: Well it changed quite a bit. I am not sure. I guess you need those. You need the decimals with the zeros. Cause 9 milliliters don't make much sense to me earlier.

Researcher: Were you expecting there will be a change when you use significant figures?

User 05: I didn't expect that. Unless the concentration written in wrong. I didn't expect be required to putting a decimal and following zeros.

Researcher: What do you think about that?

User 05: I don't … I am not a big fan of that. It shouldn't be any difference between 3 and 3.00. The way I put it. I don't know. I didn't expect that certainly.

Some of the participants become aware of the rules about formatting expressions because they expressed themselves in other than the acceptable input formats and they thought they were making other conceptual mistakes. After a trial and error period, they learned about the rules and start using appropriate input formats.

User 03: Quite basically same as the precision. [Click "*Molar Mass*" tab]. So I can enter the formula [click "*Enter Formula*" field]. I need to capitalize this formula; I don't want to make a mistake that so happened before.

However this trial and error period caused confusion in some about what they were doing because they didn't get the results expected. The problem of inappropriate input created difficulties in understanding what was happening and led their minds in another direction to check their results rather than continuing with the other steps:

User 04: [read the problem aloud], I just click "*Molar Mass*". After click on it [click] I just type the formula. I think I just need to capitalize them all [write the equation in capitals, leading wrong result]. Find the molar mass, [clicks "*Find The Molar Mass*" Button].

Researcher: Is that what you expected see?

User 04: The result should 179.805….

Researcher: Can you explain to me what is happening in the big white box?

User 04: They just give breakdown analysis of each element here. Like H… H, I think… Molar mass for H is one, right ? [Confused].. Why there is 124 for there..

Researcher: What do you think is happening ? Do you think there is something wrong?

User 04: Yeah, I think there is something wrong. Because it didn't figure out the Ba. Ba should be just one element but that analyzed as B. This is not right for the molar mass.

Researcher: So this is not what you expected to see?

User 04: Maybe it is because I type them capitalized [changing formula, Change BA to Ba and CL to Cl, click "*Find Molar Mass*" button]….

Ahhh… I think this one is right…cause when you type formula in right way it gives you right results… Ba is added to end, this is Cl [showing each of them by highlighting]… L and A [meaning for Ba and Cl] should not be capitalized.

Need For a Validation Method

Participants made several mistakes entering incorrect characters into *StoiCalc*. Unfortunately, there was no function in *StoiCalc* to validate users' input. *StoiCalc* assumes that the users' input is correct and typed using the acceptable input formats without checking the format. Both parties assume that the user inputs formats are correct by default. As in the above example, that leads to misunderstandings because participants also assumed that they had input the expressions correctly and expect *StoiCalc* to give a

result using wrong format of inputs. However, *StoiCalc* uses the expressions as they are input into to calculate the results. Another example of inappropriate inputs occurred in using zeroes instead of uppercase "O" in formulas.

> **Researcher:** Can you explain to me what is happening in the big white box?
> **User 02:** This big box shows the work done to come up with the answer [read the result], it shows you the z number of the hydrogen, it shows you the Z number of Cal, and shows the Z number of Ba. And the Z numbers are protons; here we have 40 of it. [Read rest of the Z slowly]…. Ohhhh…. I see. ..
> I entered the zero instead of O, so it calculated H 20.
> So I am going to put a zero instead of it. Oh no … instead of zero put O. And click this again [click "*Find*"].
> Now it gives me the right answer. 4 hydrogen, 2 oxygen, 2 Cl, 1 Ba.

The only way that users understood that they had made a mistake was by checking the solution steps given by the *StoiCalc*. Sometimes, however, users didn't realize what was going on in their calculation because there was no warning or indication. In the following examples, the researcher had to lead a user because she wasn't figuring out that she had entered zeroes instead of uppercase "O"s into a formula.

> **User 01:** ok I am going to do that, click the "*Balance Equation*" [click] …
> So at the top. mm… I am little confused because , I had typed in Manganese oxide up here in the reactants and it is no longer there… and this tell me the solution to my problem [showing the big white field for display].. but…
> manganese is gone . so I am trying to figure out what happened with that.

Researcher: So is that what you expected to see?

User 01: No.. [trying to figure].. maybe just it is because it goes away… I am not really sure ...

User 01: Yeah , I will click "*Erase All*" and try again . .

So [entering again]… it goes away .. . Mmm… [Confused and trying to figure out. reading result field]… it doesn't really tell me what happened to manganese. Yeah that is not what I am expecting.

Researcher: Did you put O correctly, or did you put a zero there?

User 01: [click "*Erase All*" button try again] .. SO, yeah, I guess I really did that.

So now it tells me. I probably put zero instead of O.

But really it is common mistake for me. I am not surprised with that mistake.

Users may have lots of inputting errors that can cause misleading results. Therefore, there should be some input validation method for checking the formats of inputs. Otherwise users may become confused and try to figure out a problem without the tool. Once they figured out what went wrong, they found the rest of the steps to be easier for them.

User 01: It is fairly easy. The "*Molar Mass*" is fairly straightforward and simple. The "*Balance*", I just, I had a mistake using a zero instead of O. I don't think that is specific to software. I think this is an issue I had over the years. But… once I figured out what I was doing incorrectly, it was easy to tell me exactly what I have expected to find out. I guess maybe only thing with that is I feel like that might be a problem for some other people, so it was just to say that it didn't

recognize the formula that I had entered. It would have been more apparent to me, I had made that mistake. It just threw out assuming that it can't really do anything with it. It didn't tell me what is going away or why [MnO_2] is going away. When I had some other software, if you enter something invalid it tells you this is invalid. So certainly it wouldn't tell me that so I would be more careful [the] second time I entered that and third time. Just that I can see that would be an improvement.

User 05 : It was pretty easy once I figured I have to put the significant digits in there. I was getting the strange answer in the first problem because I wasn't putting in my decimal points and zeros. I saw the answer was strange and didn't make sense, once I change it I got the answer that I was looking for.
Researcher: Do you think seeing a strange answer makes it difficult?
User 05: It was misleading obviously. I don't know if someone learning about the chemistry will recognize 9 mL to make this solution was an odd value.

On the other hand, because the only instruction about formatting inputs is online, it was probably natural for users to skip these steps before they realized there was an online instruction manual option. This very important information was only in the manual not directly embedded within *StoiCalc* (for more details about help functions, please see section titled "Help me, save me").

Researcher: Why did you put 0.45 in the concentration box?
User 01: Because that is what the question asks for?
Researcher: If you put concentration 0.450 do you think it will make a change ?

User 01: No . It won't . [Add zero and click "*Find Mass*" button].. ohm… I guess it would. I don't know why…

Researcher: Do you have any idea?

User 01: I guess technically it is more accurate, 0.450 is more accurate number. I wouldn't expected to it be different. I know going to 3 decimal places is more significant, more correct way of recording data but I wouldn't expected it would change my answer. I mean I can understand that but I wouldn't expect.

Researcher: So what do you think about the accuracy of the software?

User 01: I think it is good. It is good for students to know that there is a reason why we go to 3 decimal places instead of using 2 decimal places. It is a good thing to be aware of. I wasn't aware that was going to make any difference. I wasn't aware I would have needed that. That would be something I didn't read in the web manual or "*About*" section. That could be because I need to make sure type that as in the question page.

Also having directions and notifications about formatting input directly visible in the functions of *StoiCalc* may help users realize the rules about expressing themselves within *StoiCalc*.

User 0: I would think that not all the chemists are computer savvy. It would be a good idea to make it case in sensitive or say please type in case sensitive. But I think the result is nice…. [Continue to use]

It is case sensitive it just says here [help page], I just hoped to have some kind of a tool tip or a line in the application itself that says it, because as a sure I might

> miss that point. Sometime it is inconvenient to look up to help, we can put and argument in the shows the formula is case sensitive in the application itself.

The online manual also was the only place where the beginning tab of *StoiCalc*, which is labeled "About," is described. Users might not to attend to this help instruction in the first place. Both in free exploration and task oriented sessions, the majority of users weren't attending to the availability of a help option; they just engaged with the other functions of *StoiCalc*. *StoiCalc* design could change to make the help option available and visible in each tab.

> **User 0:** Hey there is a lunch web instruction manual button over here, which I haven't seen. [Click "*Launch Web Isntructions Manual*" button]… Instructions are given here which is nice, I should have checked that. Here is two others that I have completely missed last time, perhaps I wasn't exploring enough … But, I will be mindful of these are all around the software.

Fortunately, instructions in the Web manual directed users regarding the use of *StoiCalc* and helped them to become aware of appropriate ways of expressing themselves to *StoiCalc*. When they had a problem because of significant figures, for example, they remembered the instructions in the manual and figured out their mistakes.

> **User 02:** I see. My significant figures are reduced to 1 it gave me an answer in only one significant digit. That would be 2. In case of 1.70, when I use 2.00 and I forgotten I was testing the program to see if it would incorporate the significant

figures. When it came with the initial answer, I changed the liters and thought this isn't right. I need to increase the sig. fig.

Researcher: So were you aware that program is using significant figures to count on?

User 02: Yes. I assume this much, I could see right now. I remember the movie at the last session that it has or at least in the help page it does taking the account.

……

Researcher: So do you think significant figures really matter in that program?

User 02: Yeah. I was careful to use it before. Then I decided to test it to see if it was true, but I forgot I was testing it and it confused me why it was giving me incorrect answer. But actually it was giving me the right answers when I was changing significant figures.

Researcher: Were you aware of significant figures?

Because the about section of the program told me to use the significant figures.

Researcher: Is this what you expected to see?

User 02: Right now, yes.

User 03: [Change numbers - recalculate]...Ohh…. Ok… that is interesting.

Researcher: What do you think about that?

User 03: I remember there is a precision problem in this software. It may ignore the second zero after the dot. If I am not wrong, if I delete the second zero for that and calculate again that is a precision for this program. [Try to delete and re-calculate].

If there is no decimal the precision doesn't increase.

Based on this recipe that is something I am looking for. The precision problem makes me a little confused.

Understanding StoiCalc Expressions (Output):

Cognitive artifacts may inform users with external representations that help the users to interpret the internal processes, or available actual states of cognitive artifacts. Information given out by the cognitive artifacts may direct users' decision mechanisms and thoughts. The information given out by the cognitive artifact plays a key role in directing users to follow possible schemes within that artifact. These schemes define the steps and paths for successful task completion.

The cognitive artifact interface leads and directs users to follow structured steps by providing means for inputting data, on screen directions, or a certain manner of interaction methods. Outputs of certain functions in the cognitive artifact also lead and direct users in such a manner. These outputs help users to see what is going on within the internal states of the cognitive artifact, what are the results produced by the cognitive artifact, and what are the possible directions given by the artifact.

StoiCalc outputs rely on displaying text-based information in output fields (or boxes). Some of these output fields are directly visible on the screen; some are hidden to the user until they are needed. These hidden displays appear on screen mainly when *StoiCalc* generates results. The directions, or the information given in, and the design of the output fields are very important in *StoiCalc*. If users can understand the design of outputs and the meaning of the given information, they easily move to other steps or they can easily interpret the results.

> **User 0:** [In "*Solution*"*s* tab, before clicking the "*Display Recipe*" button.] Then I guess I can see what my recipe tells me [click "*Display Recipe*" button].

> That is pretty good. I know how much solvent I need to start with. It gives very straightforward instructions. I know how to do it for KCl.
> **User 01:** [at "*Solutions*" tab] I am going to click on display recipe [click], and it is going to tell me exactly what I needed to do to prepare that solution [read recipe aloud]. So that is good. A great descriptive of what needs to be done even added a warning in there. This one is what I am expected to see.

If there is a complication at the design of output methods, users can have some problems or interruptions with *StoiCalc* operations. The problems or interruptions caused by the insufficient design of outputs may mislead and/or confuse users.

> **User 0:** What is a little confusing is that I am not sure what these boxes are doing [yellow display fields]…. I would normally expect grams per mole. Because when you are calculating the molar mass… mmm. I am confused; I don't know what they are meaning here. Because normally when calculating the molar mass you expect this number [98.078], which is correct, and gram/mole written here [means yellow display field, at top row, second coloumn]. But they have a little thing that showing up in once in a while [means tool tip]… here there it is units for computer molar mass. This doesn't make sense at all to me; it also disappeared. But I would expect, from the chemistry background, to tell me grams/mole. It looks nice otherwise, it is simple.

In *StoiCalc*, the most critical design problem of outputs occurred because of their affordability and ability to allow users to make inputs. Users can enter data easily into some of the input boxes in *StoiCalc*. In *StoiCalc*, there is no mechanism to avoid making

inputs into output boxes, and there was no indication for distinguishing items clearly showing those boxes are only for input. For example, in the "Solutions" tab of *StoiCalc*, there is a "concentrated reagent" output field that displays the selected concentrated reagent from a drop-down option menu. This field also lets users make inputs. Entering the formula of the concentrated reagent is not directly connected to the calculation steps of *StoiCalc*. A participant replied that could be confusing when the researcher asked about this issue:

> **Researcher:** [at "*Solutions"* tab] Do you think if you type formula in the very first box ["*Concentrations Re-Agents*" display area], will it change?
>
> **User 05:** I don't think so. [Type formula in and click "*Find*"] It displays the name of the solution in the recipe but I don't think it should have any change in the math done for finding volume of stock solutions. Nothing changing.
>
> **Researcher:** If you were a student, would you start solving this problem by starting to type the formula in the first box?
>
> **User 05:** That wouldn't be clear to me. If they went to concentrated reagent menu and saw that NaCl is not there, I suppose they might just type in there. It is not clear it would make a difference in either way so they might type it in.
>
> **Researcher:** Do you think the very first box ["*Concentrated Reagents*" output field] is easy to understand or makes navigation difficult?
>
> **User 05:** First box, it doesn't really make any difference whether it is filled in or not. It is just a name of stock solution used in "*Display Recipe*". Selecting a concentrated reagent form the drop down box fills in your concentrated stock solution molarity but it doesn't really affect other than that. Inputting that makes your recipe more clear.

A similar situation arose when balancing chemical equations using *StoiCalc*. After entering all the reactants and products the participant balanced the equation by adding coefficients. What *StoiCalc* did was to use the reactant and products he entered and show the balanced equation and the coefficients for each reactants and products. Although the coefficient box was intended for output, the user was able to make an input. Therefore, after balancing the equation, he thought *StoiCalc* was just showing the balanced equation to confirm the inputted data was correct. This example shows that *StoiCalc* clearly can mislead the users in some situations:

> **User 05:** I forgot about the blue box at top! Once, I guess, it ensures the reaction that I put is balanced and it confirms at the top blue box for me [Note: He thinks the program balances the equation and confirms entries; actually, the program is replacing the coefficients he entered with the ones it calculated; he just needed to enter formulas and not coefficients!]…

The design of layout also confused users. In some functions of *StoiCalc*, the output boxes for results, which also allowed users to input, are placed at the very top and left of the screen. This layout leads users to think that very first boxes should be for inputs. They thought the first step was to make input to the *StoiCalc*, and as long as the first box in the screen allowed inputs, they used those boxes to make input. This case was especially true before they had discovered the help options of *StoiCalc*.

> **User 04:** [at "*Balance*" tab] I think these two boxes should be added in front of the screen [showing the reactant and products boxes, and meaning to put them at

the beginning before the blue display field]. This one is a result [showing the blue box]. This one is given by the computer, not by you. Those boxes are where you need to enter elements [pink and green]. They should be before the blue one which shows results comes from the computer. And also this white one. Maybe you can just combine this blue one with the white one and put them a little bit down.

….Because at first, everyone may look from beginning to the end, and if this box [blue box] are the first we also want to enter in that box and see what happen. If you can change the box for formula [designer] and move it up before the blue one, it would be clearer.

….first I wasn't aware that I could enter something in that box. I think this is just a box that computer will show us and we cannot enter into this box. So if you can change this software and label which box is to enter and which box is for computer to show us the result that we don't need to enter data.

Researcher: Is this confusing you in the first place?

User 04: yeah, yeah.

The level of user interpretation and understanding of cognitive artifacts' external representations could depend on the amount, structure patterns, and relationships, available as well as the visibility of the output information. In addition, users' familiarity with the given information, memory load, and ability to process may affect their level of understanding. For example, because of not being familiar with the representations in outputs, some of the users can't understand or they need a simplified version of the expressions at outputs where the mole - gram ratio is given in a table-like structure:

User 02: Before clicking that button, I was expecting a number here, of the molar mass. But I was not sure what these 4 boxes [pointing yellow display fields] before yet. I was expecting data as far as calculations but I wasn't sure how it will be derived.

Researcher: What do you think about these yellow boxes over there?

User 02: Yellow boxes will give your answer. The final answer. I find them very well organized. Units [showing the fields]. I don't know what the meaning of button one is [yellow display fields down row, first column]. By definition the computed mass is 1 mole. I would find it just as useful without these two boxes [showing yellow display fields down row].

Researcher: Do you think these boxes at the bottom are confusing?

User 02: Not confusing, I mean.

User 0: This is nice here [result display field]. It is a good thing to have. It is a break down of the components. This part here [yellow display fields], is very understandable because this is the some of these [yellow display field, first row, first column]… I am not sure what do they mean here [yellow boxes, top row]. Wait a minute; I think I just saw a tool tip just a minute ago.

[Mouse over wait for tool tip]

[Reads tool tip]…

Normally I expect in the calculator, the units are grams per mole, I am assuming this is just computed for one mole of this compound. It kind of makes a sense.. In chemistry, you just put it directly like g/mole. But it kind of makes sense I guess. It kind of weird this plus sign kind of a thing here, somewhat disorganized.

User 03: I am not sure what this is … Because these four column [showing yellow result fields] I am not familiar with this kind of illustration here… There is an indication of texts [units] here, the computed molar mass is here [showing the fist row of yellow display fields], units of computed molar mass are the grams [showing the "*Unit*" fields]… That is one mole of compound… what is here... .oooh ok... that means that is one mole of this material... unit is gram... so gram per mole.

Researcher: Can you explain to me what are those four yellow boxes?

User 03: That one is computed molar mass... is the summation of these elements in total. That is the unit for the computed molar mass. That corresponds one mole of this material. But I think there are may be some improvement, like not a square not a form of box, maybe there is a table [showing the result], [wording like that] one mole of this material in this gram... or they can corresponding words.

Researcher: So do you prefer verbal explanation better than numbers?

User 03: Yeah yeah.

User 03: Because when you see the gram here, you can have a phrase here and put the gram and of that mole of that material. Maybe you can also put this materials formula in the top box and /or the words of chemical formula here also.

On the other hand, some users found this kind of representation very useful because it seemed familiar to them (for more details pleases ee "User Habits and Transfer of Knowledge" section):

User 01: [at " *Molar Mass*" tab, Mouse over reuslts field]. And than this was originally an empty box.
[Mouse over to the result fields], there is the row or chart [rail road check], that is how we teach students to find or calculate the molar mass. That is nice.

Regardless of knowing what is the output means, users may prefer representations that are more familiar:

User 0: …One wish I would say is, instead of displaying 9E+02 I would prefer it to say 900 milliliters. Mathematically they are same but it is not a human way. As a human that should be a little easier to say 900.

Finally, in *StoiCalc*, the visibility of the some of the output fields should be larger to ensure comfortable reading without any scrolling:

User 0: [at "*Solutions*" tab; click "*Display Recipe*" button].
I wish this would be larger so I need to scroll to see. This is too small area to have so many instructions.
[Read recipe]…

Need For Understanding Internals

Users may assume that the design is correct and reliable. They can simply follow the cognitive artifacts' outputs without thinking that those outputs might be either incorrect or misleading. They sometimes think they do not need to check or at least think about results; instead, they assume that the results are absolutely correct. Also the

cognitive artifacts may need to provide a mechanism to disclose internal processes in order to be able to check results.

> **Researcher:** What happened when you type the formula correctly and incorrectly?
>
> **User 04:** When I did not type it correctly, this is something I cannot figure out without checking the results and it gives something wrong. If I type correctly, it gives correct elements that I want.

> **Researcher:** What do you think?
>
> **User 02:** I am trying to figure if the answer is accurate… ok. So. I don't know. I don't think that liter and L are the same. I need to find … [typing everything again and try once again to calculate]…
>
> **User 02:** …. [Thinking]….
>
> **Researcher:** Do you want to double-check the numbers you have entered? What makes you confused here?
>
> **User 02:** mmm…. I put 2 liters of stock solution and dilute it to 4 liter. Concentration should be 1 molar but it is 0.850. Unless I am just not seeing it right. [Thinking and calculating on mind]… Ok… mm.

When users made a mistake such as typing an incorrect formula, because of lack of a validation mechanism in *StoiCalc*, they need to try to double check the calculations by themselves or read the explanations of outputs given by *StoiCalc*:

User 02: When I typed wrong formula ,it didn't show me the oxygen, which surprised me because I expected to see a scroll bar [meaning in the result field] when I was doing this like the last time, and I was wondering where the oxygen was. I found that the oxygen was not present and it gave me an incorrect answer for the molar mass of [reading formula].

…..

OK... Just double-checking. We have 6 carbons over here on this side we also have 6. We have 12 hydrogen on this side also we have 12 H on this side. We have 18 O, here we have 18. .18 and 18. So it is balanced… solution is correct. So here is the answer, repeated from the blue box [showing the one in the result field], the procedure again, shows you the number of reactants and products. 2 products this time

Researcher: Is that what you expected to see?

User 02: Well... yeah… I expected to see a result but this one I could calculate before hand. After confirming this, I can say I expected to see this correct result.

Users need to interpret the internal process of cognitive artifacts in order to understand how the artifacts came up with their results. That is, which algorithms and steps are used, what are the available options related to actual state of the artifacts, and what is the next possible best step? Understanding an artifact's internal states also is helpful in user decision making processes. In order to disclose the current states of the artifacts, there should be some output express this state to the user. These outputs could be in the form of on screen directions, tool tips, or pop up messages. *StoiCalc* has some partial mechanisms for expressing its internal operations to users. For some functions,

StoiCalc explains problem solving steps and the algorithms used to come up with results. In other functions, however, *StoiCalc* not follow this approach.

> **User 01:** It helps you make sure what you have done is right. The "*Molar Mass*" shows you how the math has been done. The "*Balance*", definitely I feel that it gives as much information there. "*Chemical Reactions*" are not showing you how to do the math. So it is going to help you to check your answer but it is not telling you how to do the math. That's what I think would be vital for improvement if you use this first before your own doing the problem.

> **User 03:** [at "*Chemical Reactions*" tab] it is quite simplified but for chemistry students without experiencing paper calculation they will not be sure about the answer because this is too direct. It is not like the balance function [tool]; after you give the formula, the coefficients are shown in mathematical way. There is no procedure showing how the computer solved the problems [at "*Chemical Reactions*" tab].

For example, the "Solutions" tab of *StoiCalc* doesn't give any clue about the steps for calculating the results. It merely presents a recipe for preparing the solution. Users sometimes may need to refer to other functions of the program to check their problem solutions, especially when there is no explanation for each step. One user felt that she needed to check the calculations for molar mass of the solution that is not directly described in the solution tab. Therefore she decided to go Molar Mass tab of *StoiCalc* to check the results:

> **User 04:** So in the previous section I can double check the mass of this formula [click "*Molar Mass*" tab, enter formula in "*Formula*" field, click "*Find Molar Mass*" button], enter KCl and click find molar mass, that is what I expect. Click back to solutions to see if this is correct [click "*Solutions*" tab]. So this is correct. Ok.

In addition, some of the *StoiCalc* functions explain the steps but users have problems in understanding the algorithm and its logic because it is a new concept for them. It could also create confusion and/or a heavy memory load for some users. Both in *StoiCalc* output for explanations for the steps and manual help pages, there is no clear information that explains these kinds of algorithms to help users to understand the concept.

> **User 01:** So when I click "*Balance Equation*", the balanced equation appears at the top in the blue box. And it goes the same in the solution in that white box. So it shows the procedure, the number of reactants, and number of products. Conservations equations; I am not rally familiar with the conservation equations [reading matrix]. Let me click on manual to see if it tells me about this. Yeah. It doesn't tell me what it is about.
>
> But I can see here in this [image of matrix], but it says the explanation. But I guess I am not just not familiar with these terms. I am checking to see that. But I am not really sure what that means.

The "hidden" algorithms come up with solutions that make some users curious about discovering more about the calculations of *StoiCalc*. Again, they thought there could be some hidden explanations in *StoiCalc* or its online manual:

> **User 02:** Really interesting to me is the conservation equations table. And that is just because I am not familiar with it; I'd like to find out how that works. But I am not patient enough to watch another video [might think that there is a hidden information about that "*Conservations Equations*" table in the video].
> **User 02:** I am very interested to learn how they calculated the coefficients with this "*Conservation Equations*" table. First thing, I read the solution [highlighting the solution in the white box] and that shows you the number of reactants you have, the number of products. And here … [reading the explanations about the *"Conservation Equation*" table]…. OK…mmm. I am not sure. I know it balances the equation but it does so in a way that is unfamiliar to me.
> But I will definitely remember this term [meaning "*Conservation Equations*"] and I will look it up.

Especially those artifacts that are designed for helping students with problem solving should explain the results and the steps taken during the problem solving process. It is critical that it needs to present explanations of each step more deeply than just showing an end result. Students need to know each step behind each function that is connected to a button (except the buttons like erase all or import equations which are not really directly related into the problem solving process). The artifact itself should have a

mechanism to show each step where it gives an explanation to students to make it easier to understand the relationships between each function connected to the buttons.

> **User 05:** Well… It is certainly much faster and much easier but you don't get to see the process that students are getting through. If they (students) are just putting some data in these boxes. That would be useful to see if they understand that process. Without any understanding of how it is working, and you know what input and what output you are looking for, you use it without understanding any of concepts behind it.

All of the users thought that some of the internal mechanisms of *StoiCalc* were "black boxes" for them. They indicated that they needed to see internal calculations, descriptions of each step in problem solving, and the arithmetic involved in problem solving mechanisms of *StoiCalc*.

> **User 05:** Any improvement came through software would be, it can just confirm if I was correct or not in my calculations in paper. I don't think it doesn't walk you through the math here. If you don't understand the math, it is just like black box. If you don't understand the math it can only be used to help check your answers.

> **User 0:** [at "*Balance*" tab] I kind of wish they show the summation process here. But it is not a necessity it is just a wish list. Because it will nice to know I am adding 2 H, 1 S and 4 O. That maybe useful
> I have hydrogen and oxygen and gives water and that is great. However in the balance I would expected that you have one mole of [because he didn't push

"*Balance*" button and there is nothing in blue box now] half mole of oxygen; I wish it showed how we get the formation of water in formula. .

Researcher: You didn't click the display recipe button, what do you think this button does?

User 04: I think it should show the details of preparing this solution.

Researcher: What do you mean?

User 04: Yeah, just like the molar mass and the balance. Just show the detail and how it does that.

Researcher: So what are you expecting?

User 04: A mathematical method?

Researcher: Why don't you click "*Display Recipe*" button ?

User 04: [click" *Display Recipe*" button].

Researcher: So what do you think this button does?

User 04: It is telling you how to prepare that solution.

Researcher: Is this something you expected to see?

User 04: Not exactly the same; I think it should be just a number. This description is a direction that tells you how. I think this is better. Because this description tells you exactly how to prepare this solution.

It is natural that users and especially students want to double check the results as well as to understand what is going on in the internal process of the software. All the users wanted to know if their results were correct so they needed and expected to see the steps to solve problems in *StoiCalc*:

User 0: Maybe, I think that answer is not correct because you have 40*1 that is 40 units of H, but I know O2 is I think 16. 16 * 4 should be 64; plus 2 that is 66; and the S I think is 32 so 66+32 would be 98. So I think you need to check your calculations here.

It has got exactly what I want; it has got a break down of each of the atoms. It shows me break down of H, O and S. So this number makes sense. When I was calculating on my hand it would be near to 98, this is exactly what I want.

User 01: and I am expecting, mmm… showing that how to find the molar mass of it.

[Clicks "*Find Molar Mass*" Button; user moves mouse over to the result steps field and she sees the tool tip.]

User 01: So I have a break down based on atomic number, masses, and then the number of atoms that are in this chemical… and takes the number of atoms... The number of atoms times molar mass that gives me for the Hydrogen. And then here for oxygen, there is 4 oxygen takes those times molar mass. Gives me total for oxygen and same for sulfur. Takes there is one. And takes that time the mass there...

[User moves mouse over to the result field. Move mouse to indicate result fields one by one and starts explaining the results.]

User 01: Here is the total of all of these [moving the mouse over to the result steps field]. All those different elements out of that. There is the 98.078 g of hydrogen sulfur I believe. Sulfate, sulfate. And (in) 1 Mole,

Especially in the case of system operations, *StoiCalc* gives no clue to the users. For example, it doesn't give any clue like operations of "Import"; it doesn't tell you when it is calculating, when there is an error because of an internal failure, and whether it needs a user input.

> **User 01:** ["*Erase Fields*" pop up] I don't understand why that is popping up all the time [click "*No*"]. This time I didn't click on the Next box ["*Volume*"] volume box. I actually clicked find the molar mass button and message popped up and says "erase other fields." I can see that being helpful if you had been going from question one and you hadn't erased everything, but I had clicked on the Erase all button and still getting that message. I don't know why that keeps coming.

Help me, save me:

This section describes analysis of user's interactions within the web instruction manual.

StoiCalc doesn't make a perfect job of directing users without any interruption and any confusion from the starting point to the end results. As described above, users had some problems in understanding the ways of expressing themselves to *StoiCalc*, in understanding the internal processes and problem solutions steps, and in understanding how *StoiCalc* expresses itself to users. Participants didn't attend the help options given in the web instruction manual which isn't clearly visible in the "About" tab and which is not accessible directly from each functions of *StoiCalc*. However, in Task 1.2, users were directed intentionally to the Web instruction manual and were required to use the Web

instruction manual options. After realizing the presence of the help options, some users referenced that help page frequently:

User 02: So I am going to put a 100 here [Hit Enter, Type 100 "g" in "*Mass G Before*" field].

Now I will see if this button works [Click "*Mass Products*" button.].

[Nothing happens]… Ok, it doesn't. Sooo… [Confused and stopped]

[Read tool tips for "*Find MM, REM and Mass Products*" button.]…

So how to have the program calculate the mass of products. I am going to consult the instructions [Click "*About*" tab, click "*Launch Web Instructions Manual*" button].

[Go to " *Chemical Reactions*" at the manual]…

[Reading helps page aloud]…

Ok… Sooo.

[Go back to StoiCacl]…[Delete the "g"]

[Delete 100 from "*Mass G Before*" field]

Researcher: Can you explain to me why did you consult the help page?

User 02: Because when I push mass products button the mass products didn't show up and so I thought there is something really simple that I was missing. May be a field I didn't enter or may be I didn't need units which seems to be the case. I took away the grams now I am guessing the "*Mass Products*" will work.

Researcher: Why did you delete "g" and "100" ?

User 02: Yeah, the manual says the all-mass units are the same.

Researcher: What do you think about the next step?

User 02: I think the next step is "*Mass Products*". [Go back to manual, check it again, and read aloud]

Some of the users read the related help pages before engaging questions. Others just used the help function whenever they didn't know something about *StoiCalc* or whenever they felt they stuck.

Users first thought that the help pages in online manual were for directing users about how to use the software. Participants also anticipated that there would be some additional examples, explanations, and some information about the chemistry contents in the help pages.

User 0: I probably click different buttons on the top ["*Tab Bar*"]; I may go sequentially to start as what it tells me. I will start about and I am assuming it will let me something about how to use the program, how to enter data and explain each of the sections to me. So I will click about [click "About" tab].

User 05: So. I am looking at the *StoiCalc* program. It has a menu bar on top. Theirs some options [reading the tabs one by one]. If I was going to learn about this program, I probably would go to about and start to read this section. I hope it has some general information about each of the topics or maybe some of the usefulness of the each of the tools and abilities. And I go there [click "*Abou*t" tab]. I found here what I expected; it has synopsis of what all the major functions are. I will read over the heading [buttons to launch tools], and see what is going on each one of these. But they all look similar. I am familiar with the vocabulary. I have a good idea about what each one of these are going to do.

> **User 03:** I will click on the "*Launch Web Instruction*". [Clicks the button]. Ok so It pups up an online manual. Some kind of help for this software. So there is this kind of manual for the software. This about is something different on the software [meaning the about tab in *StoiCalc* and about tab in the web manual]. In the manual there is introduction for the chemistry. So that is some basic instruction for those who are not familiar with chemistry, notations, and formulas.

Participants also indicated that there could be additional explanations and examples about the *StoiCalc* rather than just how to format and enter data.

> **User 01:** Exploring Molar mass [watching the "*Molar Mass*" tab]. I know that movie would tell me how to use molar mass in software. It is telling me exactly what I think it is going to tell me. It is showing me examples. …

> **User 05:** There may be some examples in the help that I just didn't see. I was stubborn to look at the help initially

Users of the web manual have two options to learn about *StoiCalc*. The first option is a combination of descriptive text with images. The second option is video. Help pages lead users to decide use text – images descriptions and/or videos. In this decision process, there are two manipulating factors to decide which option to take. The first is the design of the help pages, and the second factor is the participants' personal choices.

The design of the help pages, especially the design layout, helps users recognize the video options. Some of the users had difficulty finding ways of accessing videos from help pages.

> **User 01:** A mainly option with these pages is to read it. I don't see any movies in this web page [scrolling down and up]… Basically the main option is to read this page so I know how to use the software.
>
> …
>
> **Researcher:** There is actually a going to top option and a movie option in that page, but you haven't recognized them in the beginning. Why?
>
> **User 01:** ohh... I guess... I would have just expected. I think it [should be] kind of like when you have the *YouTube* video embedded in something.

Users' personal choices related to their attitudes toward text and/or video. Some of the users like watching video while others preferred using text – image combinations.

> **User 01:** [watching video]... Ok so as far as everything is same what I have read. That was good to hear he is explaining because I want [to be] exactly sure what combusting product is referring to. So by hearing him saying, I understood better than I was reading on the page.

Moreover many participants thought that the text descriptions in the help page of *StoiCalc* were quite long and indicated they did not want to read all of them.

User 0: … ohh. That is really nice because what I am happy about this video, I don't have to go through the entire write up [text]. I personally prefer video before[I] read all of [the] text. What also helped was the instructor moved the arrow to different places that are really nice.

User 05: I was aware of that movie button. It is not the most obvious thing; I was more interested in formatting.

Researcher: What do you think those movies are talking about?

User 05: I imagine the movies just take you through maybe an example of how to do a problem. I can imagine it shows you features that somebody talking along or moving the mouse along while showing you what to do or how to do different kinds of problems.

Researcher: Do you think there is something more than the text, or it is the same?

User 05: … I imagine it is pretty similar to text. Just with someone talking along. I feel like I got most of the info I needed from the text page.

Researcher: Do you prefer the text or the movie?

User 05: I like them. It is not bad to two have both, but I with text I can jump around more easily and see or find the specific answer I am looking for rather than having to watch a movie. It already had a lot of things that I already understand and I don't need a movie.

User 04: For the software. "*About*" [tab], I was not sure what the directions are for. I may not read them all to navigate. But the help pages are Ok. I can read descriptions after clicking tabs. Because they have text, graphs, arrows and this is

> very clear to find your way [by looking to page graphs]...Because some people don't like the words in the directions. Just may need the graphs or just to see examples to know how to use software and where to go. If I have a direction I can find my way easily? Yes. …
> I think this is too much. Because when people first see this, they don't want to read too much about the help. I think just one simple example is good.

Similarly, some of the users thought that the video files were too long to watch. A user already suggested splitting videos in a step-by-step fashion so users can reach the steps they need to learn directly without watching unnecessary parts.

> **User 01:** I would like that video is shorter not like one in the balance equations. I think that video could be working into a couple of shorter videos. If I had a only a question about composting products it would have been nice to go straight to that video instead having to watch all the video. Because I think it is like 5 min. video. But this one is only 2 min. It will be helpful if shorter. I know this has only one function, molar mass. But when there is a multi function, it would be nice to be able to watch video for all separate functions. Like I know basic parts of the functions, but what about for more complex features… For example, now I am going to combust this, and I know the basic parts, but I wasn't exactly sure about combust. I like that he explained it in video but I can directly watch the combust part.

Also, users might not remember all the steps described in the videos. In one case, a participant had difficulties remembering correct order of steps after watching a video.

User 0: [At manual, click "*Chemical Reactions*" tab at the manual]
From my last session I have figured that it was easier to understand from the video.
I will watch the video and see what I can learn [click"*Watch Video*" button.]
[Watching video].
Ok. This is actually quite helpful. I know how to use it now. I do go back to chemical reactions [go back to StoiCalc].

For example we have [reading coefficients of atoms.]… Now you have to see. I hope I remember this. [Click "*Mass Products*" button, nothing happens]… Nope. That is not right…
Maybe I forgot it … [click "*Find MM, REM*" button]. There we are. I used the "*Find MM, REM*" button and I can see the values now. I do know the mass grams before for the benzene that is given here, it is 7.71 mg. [type 7.71 in " *Mass G Before*" field], so mass products would be this, [click "*Mass Products*" button]… Here g [in the title], it is basically same in everything in its scales, like it says in the video. I am not sure how many people would retain everything that was there in the instructional video. For example I have forgotten the find MM part, this button ["*Find MM, REM*" button]. So it might be helpful to figure how you can keep it in mind. We may say there [title] like Mass, instead of Mass g.

Researcher: Did you find what you expected to see?
User 0: Actually yes, although I didn't exactly remember what "*Find MM, REM*", is it took me a little while to figure that out. It is basically very much in tune with what the video said.

Not remembering all the steps could a problem of retraining what is described in the video to working memory limitations, or it could be a problem of split attention between tasks. In order to address these kinds of problems, maybe the artifact itself should have a mechanism that describes available actions and functions within the artifact. For example, *StoiCalc* could include directly embedded on-screen, step-by-step instructions rather than using a Web manual. Moreover, there could be some animation or video in *StoiCalc* itself that points and describes all the interface items on the screen as in a step-by-step walkthrough fashion.

> **User 01:** I am going to read the about and look at the web manual to see if I'm entering in the right spots and see if it'll give me some more idea about what I should be doing different…
>
> Mmm. It wasn't clear to me that mmm that I needed to do step by step procedure. And it wasn't mmm like I said it make sense if you have to find molar mass and then reaction equivalent mass but I just thought it was two different functions with and this portion of the tool. Ultimate function. So yeah. I don't know maybe it would be helpful to have just a little blurb area saying that you just need to enter in the formula, you need to balance the equation and then find the molar masses. Because I just I don't see students going to the web manual until they are really stuck. And so I can say that it would be a problem for using this program. Like you know I just umm. In just some of the different screen it hasn't been clear what to do I think that it is not necessarily putting the web manual within the program it is just like where you need to start kind a thing. Umm so that would be helpful.

There are some functions in *StoiCalc* that participants couldn't find anything about how to use at the help pages (such as "Import Equations").

> **User 0:** I am kind of carious what the import equation is [click "*Import Eq.*" button], mm…. but I have to look for that in help file… [Can't find the related information]

Because of the lack of clear directions in all functions, participants found that the online manual was the only clear information source about expressing themselves to *StoiCalc* and understanding *StoiCalc* expressions. Some of the users employed the help options whenever they became stuck in *StoiCalc*. They indicated that, after reading the help pages, it was easier to understand *StoiCalc* functions.

> **Researcher:** Do you think you were lost in the software?
>
> **User 04:** No. Cause help page made it easy.
>
> **Researcher:** Can you do it without the help page?
>
> **User 04:** Yes. Maybe I can find my way, but with help page it is easier.

> **User 0:[**Answering interview 1.2, question 1**]** It was quite easy; with the help file it was very easy.
>
> **Researcher:** What makes it easy?
>
> **User 0:** Without the help file it is not very intuitive except for "*Molar Mass*" and "*Balance*". The help file, especially the video, makes it much easier; you know exactly what to do. Video is very specific; I think even a freshman or even

younger maybe can use this like 10the grade as long as they are also taking basic chemistry lessons. It is quite simple and straight with the help file.

User 01: Definitely answer some of my questions that I was exploring last time in this web manual. It answers what I would need to do when I am unsure. I would pull this out and it would be good when I got stuck on something. It would definitely show me what needed to be done. I wouldn't have any question if I looked up this.

User Habits and Transfer of Knowledge:

User 03: "….Typing formulas is different from the one in textbooks; you have to write capitalized ones, and you cannot use lower case formula. The formula should be written in the computerized way which is given in the about page of help manual. There I can see how to write different formulas. For the "*Balance*", I don't have to write plus sign. The reactants should be written in each line split."

In order to be able to use a relatively new cognitive artifact, sometimes users need to modify their habits and past experiences with similar cognitive artifacts. As participants move toward *StoiCalc*, there were some cases where they tended to transfer their pervious habits with similar cognitive artifacts to *StoiCalc*. They expected their past habits also would be valid with *StoiCalc*. Some of the past habits make no difference in problem solving steps:

Researcher: You haven't used the "*Erase All*" button. Why?

User 02: I did see the "*Erase All*", I didn't use it because it seemed like the program would calculate without clicking it. I was lazy to skip this step by just highlighting it. I guess I could have erased all. And I put my cursor over here [pink field for input] and start entering formulas for the problem. But instead I moved my cursor over here [pink field for input], erased them. Not logical. I can't really say why. I know I could erase all [click on it]… I suppose if I would keep working on problems I would still use highlight.

User 0: …. Also I was checking this, if I could resize the window, which I can but I kind of expected to things can be re-scale when you increasing the windows size. I thought these elements in the screen also re-sized when you resize the window. But they are not.

On the other hand, some of the user's habits may create confusion, misleading results, or failures in *StoiCalc*. Some of the users intended to continue to follow their habits of writing formulas in traditional way as they had learned from textbooks or in their chemistry lessons. This led to failures in *StoiCalc*. In fact, users had to format their expressions in acceptable formats.

Researcher: [Researcher realized that in "*Balance*" tab when inputting reactants user tried to write a plus sign after products, and then she deleted it]

I saw you put a plus sigh in the pink box. Why?

User 01: mmm… I really try to remember. I didn't need to really write as actual equation format it is given to me here [in the question]. But I needed to break it

down by the different molecules that are present in the products. So I just typed +, and erased it, I was just like OK,

User 03: [When entering formula] I think, we enter formula and get product formula. So what I can type is the formula of reactant and formula of product. Maybe I just want to try that H + O [entering into pink input field];
I expect water for that [enter H2O in green input field]… So click button . So this is the solution [reading the result in result field]… but I type 2 of it …
Researcher: Is that what you expected to see?
User 03: No, because software recognize H2 + O2 as one reactant. So certainly that is two reactants. Certainly that is not what I expected.

In another example, a user tried to add units of measurement in input units because that likely was his previous habit when solving problems.

Researcher Note: [at "*Chemical Reactions*" tab, user tries to add gram unit, tried to calculate with it but didn't worked out then he recognized and deleted these units]
User 02: There we go… So the "g" screwed me up, it is not necessary. Including units…

In the following case; the participant tried to enter the formulas into *StoiCalc* as she does generally when writing formulas in chemistry lessons. However this format is not an acceptable format for *StoiCalc*. Attempting to carry past habits to *StoiCalc* made the participant confused and resulted in unexpected outputs from *StoiCalc*.

Researcher: [at "*Balance*" tab, user start typing formula]

So what were you thinking to enter formula like 4Cr + 3O2?

User 04: Because chemical equation is like that in the question. I just copied that.

Researcher: What is your next step?

User 04: I went to manual because I don't know how to type an arrow. I just open the help page to see what we should do.

Researcher: In help page, what were you looking for?

User 04: I just was looking for the arrow or how to format the formula equation in the help page. [Reading help page]

[Jump to the picture in Click "*Balance Equation*", look to the picture of "*Balance Equation"* which is Number 2]. Ohh. There are space between the numbers and elements.

[Writing equation exactly seen in the paper also puts arrow]…

The design of *StoiCalc* might benefit from these pervious habits of users to make adaptation period shorter and to assure the learnability of the program become easier. Considering these user habits could also reduce memory load of users because of reducing adaptation and search processes.

User 0: [at "*Chemical Reactions*" tab] Actually what occurs to me, as long as we read from left to right it will better to put reactants and products titles to right? That is just a personal preference I guess.

> **User 05:** [at "*Chemical Reactions*" tab, user enters reactants and products into the table, user expected to click the next line of the table to be able to enter data] More often I am surprised that you can't just click the next line in the coefficient of the formula box you have to press enter to step down. I figure I just be able to click there but whatever.

Similar to previous habits, transferring previous knowledge is very important when using cognitive artifacts. If users have prior knowledge that may be helpful in understanding the use of the cognitive artifact, they may transfer that knowledge. As long as all of the users were familiar with the contents given in *StoiCalc*, it wasn't unexpected to have a transfer of knowledge of the concepts. On the other hand, some of the participants also transferred prior knowledge from using different cognitive artifacts:

> **User 03:** Scientific notation. Conventional notation number expression changes when you use it in computer to E [exponential]. This is quite understandable. If you use "*Excel*" files, you know the scientific notation should be written in this way. That makes sense for me.

> **User 0:** [While engaging free exploration at task 0.2, at "*Formulas*" tab]… Oh wow, a whole periodic table is here ["Formulas" tab] that is nice I am assuming it pops up, oh yeah… This button is what I actually have seen in the application but I was not quite sure what it is but now I see here what it is for ["*Periodic Table*" Button]

Finally, some of the participants expected that *StoiCalc* would have a way of presenting the same or similar information that they had before, probably because of thinking that information is very useful to know:

> **User 0:** [When explaining his thoughts about the recipe given at the final steps of solutions function]
>
> If you are going to mixed acid, you should say that you need to add it slowly, it is a safety perspective, and otherwise it become really hot and may crate an accident. It is not a good idea to add whole bunch of it at one time. Not in this example, but there should be some kind of a recognition system like if you are using an acid to dilute make sure you include a safety line and highlight it in red or something.

Happy Ending: (StoiCalc as a cognitive artifact).

As the literature reviews describe, we use cognitive artifacts because they help us to increase our thinking capacity and to overcome our limitations in problem solving and decision making. Moreover, they aid memory, attention, and information processing, and they improve cognition. They utilize the processes of thinking, remembering, and problem solving, and can help to minimize errors.

As the previous section (expressing you to cognitive artifacts and understanding cognitive artifacts section) describes, the interface design of *StoiCalc* leads users in their thinking and problem solving processes. This section analyzes how *StoiCalc* helps and aids them as a cognitive artifact, regardless of good or poor design.

Everything StoiCalc does, it does it for you: StoiCalc Simplifies Steps

Helping users to simplify the steps in problem solving is what *StoiCalc* is designed and created for. *StoiCalc* basically does the job for users so they don't have to calculate anything manually to solve problems. As all the users describe, *StoiCalc* does the math for them, simplifies the steps, and gives direct results in an automatic way:

> **User 0:** [at "*Balancing*" tab] These are very straightforward equations. What I could imagine if you had very complex reactants or products, complex like very large molecules that might be something of a pain to balance. This type of simple reaction is fairly easy. I would say the interface makes it easy. For balancing it is actually fairly straightforward. You just type your data in and hit a button then you got what you look for. It couldn't be simpler than this.
>
> **Researcher:** What happened when you clicked on the "*Find Molar Mass*" button?
>
> **User 01:** [at "*Molar Mass*" tab] it basically did the math for me. It brought up the molar mass of each element. And then it calculated it. And then it just made the total calculation as well right there.
>
> When I clicked find molar mass it just pulled out the information of the different elements' atomic numbers mass, did all the math for me, and it just simply added everything up.
>
> **User 01:** I thought that it was especially easy because all I have to do is typing the problems. It basically does the work for me. If you didn't type incorrectly, you will be able to find out instantly what you are looking for. Which is really nice. It is not like - here is the step one, and out to step 15 you finally find the answer. It is all there in the same screen in 2 or 3 steps in order.

….

[at "*Balancing*" tab] …. I would normally have to find molar masses on my own. I will have to find molar mass, multiply it by the number of moles there are and then I would have to figure out how much the product would be produced. Obviously I don't have to sit down and write down the railroad check and I don't have to calculate anything, it did all that for me. So I guess that is how it would have been modified.

… Balancing equations is definitely a lot easier. Because at times when I am sitting and looking at a chemical equation and trying to balance it, especially where you have to multiply half of it times by half in order to balance everything out all the way across the equation. That is a lot harder. Usually you have to try two or three different things. It really helps like -- Ok -- this is exactly what it is, you have no question. Especially for like checking it, this would be a lot easier because it sometimes tells me Ok this tells me answer but it doesn't tell me breaking down how it did it.

Researcher: So using these tools, is there any change in your problem solving?

User 02: The most obvious change is I don't longer have to balance an equation or determine molar mass. I can simply ask the software to do it.

…

It balances equations for you and takes a lot of the intermediate steps out of the process such as looking at a periodic table. Starting with atoms that are on both sides of the equations it takes a lot of practice to balance equations, a lot of familiarity with the periodic table, so that is how it is different. But they are very similar orders in steps how to go about to solve problems.

User 03: For this software, it makes simplified every step. For example, when given reactants and formulas you are not familiar about you just have to enter the formula and find the mass. It is quite easy way to do that. But I think there is some improvement for that, if you don't know what is the formula, instead of typing showing them in a table and clicking them would be a better way. So the software makes me think in simplified ways, I don't have to remember all the molar mass procedure for solving problems or how to balance an equation. All the things are automatic.

…

The software is powerful for balancing equations, molar mass, chemical reactions and solutions problems. The paper calculations you have to know all the details but in the software you don't have to. The software consists of many functions you can use in many different respects. For the chemical reactions, there is no need to check the periodic table, no need to make the calculation for the mass, which is time consuming. In the software these things are quite straightforward. There is no need to calculate eve details and math. It is quite simple for that.

…

In the real life chemistry experiences, relatively difficult equations are very time consuming to solve. You just click one button and you get the results.

I think main purpose is making the calculations easy since you have lots of things to do to solve problems in experiments…. I remember my high school years; you have to exactly calculate the mass for the reactants so this makes them easier.

User 04: I think that if I use this software it will change my way to calculate the reactions…. If I had this program, I would not have to do the mathematics and

paper handwriting. If I use the software, I just have to enter the formula and the mass here [showing input field].

Researcher: Tell me about the unit menus?

User 05: [at "*Solutions*" tab] If you don't have some metric measuring tools around, and if you going to do some strange things like quarts or gallons, it saves you a lot of work doing strange standard de-metric measurements, so that is pretty handy. Having millimole and micromole saves you doing calculation; it is all pretty handy especially standard measurements. Because those are… I don't remember standard conversions for those and those are pretty tough.

StoiCalc also helps to reduce and simplify the amount of interaction required to perform problem steps and calculations. For example, in "Balance" and "Chemical Reaction" functions, when there is a combustion in equations, *StoiCalc* simplifies interactions by reducing the required input data by predicting combustion products and adding oxygen as a second reactant:

User 03: I just give the reactants, and click on combustion products. Water, O2 and CO2 entered automatically. It kind of has simplified the way, you don't have to write all the things in step by step, so it's kind of automatic way for the combustion equation.

User 05: ohh… I guess this is a combustion reaction so I guess I don't have too put in the O2 or H2O [delete O2 from pink box]. I just can put the first compound is. I will click the combustion products … I think it will give me,

based on help video actually, O2 as reactant and CO2 and water as the products of the reaction. [Click "*Combustion Products*" button].. Yes, that is what it did. It put O2 to the reactant side and the products that I mentioned before.

Researcher: Why do you think you need to click combustion products?

User 02: Because there is really no equation to balance at this point and I need to have products. I am going to be lazy a push this button and it will put them in for me.[Clicks "*Combustion Products*" button; program enter products and reactants].

StoiCalc also help users in decision making processes and reduces their cognitive load by providing a direction in complex situations. For example, in the "Solutions" tab, when users display a recipe for a solutions, *StoiCalc* describes for users the process of preparing their solutions:

User 0: "*Display Recipe*", this is actually straightforward. I have seen the help files, ofcourse. This point of time I am thinking this is a really good tool to have because normally what I do is, I have to find the molar mass and use a calculator. Using this particular software it is very quick, right now I am wishing if I could make some, for example, a buffer which needs two or three salts at the same time into a solution; that would be a great thing to have. For simple stock solutions this is prefect actually.

User 04: I think this software gives us a convenient way to calculate solutions problems and it gives you clear directions. If you want the solution you just need

to enter your units and click the buttons and it just go and give you numbers to prepare this solutions.

The power of Computers: StoiCalc Overcomes Limitations of Calculating Slow:

Many (not all) of the tasks performed by *StoiCalc* could also be manually calculated without major difficulties. On the other hand, related to simplifying steps (see above), what makes *StoiCalc* powerful is the ability to calculate rapidly. *StoiCalc* expands users' abilities beyond their biological limits benefiting from the calculation power of computers. When they are asked about what makes *StoiCalc* easy for them during the Think Aloud sessions, the calculation speed of *StoiCalc* is cited as a main factor for *StoiCalc* being appreciated by the users:

User 0: First of all, it is nice to know there is software to do it. Normally I spent significantly more time, especially for the "second" equation you have to balance. I would spend more time than when I was using the software. If I had this at hand, I would use the software over trying to do it with pen and paper.

User 01: I would say it is definitely a lot quicker. Because I wood be doing everything that the software is doing for me. The molar mass would take much longer.

…

User 04: …Balance Equations and molar mass can take a lot of time normally, if we use software it can't take that much time… You enter just formulas in the boxes and it comes up with the results. That is really good for a student, saves a lot of time for calculations…

This software just gives us the direct results, we just enter the formulas , reactants and products.

…

User04:

If I don't have this software, I will us the old way for math calculations. If I have the software, I will just use the software to solve problems. It will influence my way for calculations. It saves a lot of time. I think I learn better because it has more efficiency.

User 04: I think for me the most important benefit is to save me a lot of time to calculate molar mass and balance equations. When you have enough time, you can just read the details of the analysis [in white display field], you may learn why these results are given. If I don't have time I won't read these [explanations].

…

User 04: This will change the students' way to do chemistry problems. It is a really a big revolution, I think.

Researcher: Can you expand about this?

User 04: It will change the whole way of students' to do chemical problems. They are no longer need to use the old way of calculation which is a waste of time, I think.

User 05: You type in the formula and you click find the molar mass and it gives you answer like that [snapping his fingers]. It gives the answer for you. It is so much quicker than having a calculator and to do that. The balance equation is equally useful and very quick. Besides the labeling it was pretty easy to use.

…

Researcher : So what d you think about that [Matrix Equations in "*Balance*" tab]?

User 05: It is much quicker. I appreciated it. Solving a matrix takes a little bit of time, using the computer to do it is very quick. I appreciate that.

User 02: Balancing equation isn't difficult. Finding the limiting reagent, finding the mass of the products would be very helpful tool. It is not hard, but it is just time consuming. So to calculate the mass product is sense to me, it saves a lot of time.

User 02: … If there is something especially easy, I am going to assume saving time. The find molar mass makes this solution calculations especially easy because it is just time consuming and using this button [find molar mass] to calculate the molar mass of whatever the formula you punched in there saves time as far as epically easy in the case of difficult calculations.

User 05: Well , it provides you very quick calculations that would require a lot of referencing to periodic table. Tons of calculations would save your time, especially finding molar masses. Being able to have just typing numbers in and getting the answers by just clicking buttons are very handy. This "*Chemical Reactions"* [tab] is also very useful. If you do these calculations it takes some minutes, doesn't about the seconds. The time you would spend here is just inputting the data. It is very fast at calculation.

The balancing is also very handy, it does some math you might not know instead of guessing and checking method. This guessing wasting a lot of time, this gives you very quick answer. Even shows you the math involved finding the answer,

which I liked because when I learned balancing equation I didn't learn any math to do it.

User 05: Over all , I like it because it could save a lot of time. It just prevents errors, if you input all your data in generally well-labeled fields. You get your answer much quicker that you could get on a calculator without error so that is useful.

StoiCalc Saves The Day: StoiCalc Reduces Errors in Calculations.

We expect cognitive artifacts to behave in the same way in every time. In ideal situations, computers behave in a certain way without any change. Ideally, computers are not affected by external factors, and they don't lose their attention and focus. Ideally, *StoiCalc* is also expected to have no errors. Moreover, for problem solving steps, *StoiCalc* provides schemes to users. In ideal situations, these schemes are expected to be designed perfectly without leading to user difficulty or confusion. These schemes can lead users' minds and focus their attention when they interact with *StoiCalc* (see section "The StoiCalc Interface Leads the Mind"). This reduces opportunities for errors. As expected, users explained that they thought *StoiCalc* helped them to reduce errors:

Researcher: Do you think students make lots of mistakes on calculations for molar mass or balance equation?

User 05: Yes, they make a lot of mistakes. A lot of people cant sees just how to balance it .If you are not good manipulating variables in your head balancing equation can be tough. If you were bad putting numbers right into calculator molar mass would be tough, too.

Researcher: When you start learning these were you making a lot of mistakes?

User 05: Balancing equations was always tough to me. We never really taught a good method to balance an equation. It was just play with the variables until it worked out. You never had an algorithm to find it. Now software has a matrix, there is a clear algorithm to follow but I don't know how many high schoolers benefit from it. I think they could probably handle that. But I certainly didn't learn these things when I was learning balancing equations for the first time.

…

Researcher: What do you think about that software helps you to reduce mistakes?

User 05: If you input everything in correctly, it make far less mistakes, the computer does it far quicker job than the students, especially if they learn these for the first time.

Researcher: Even using calculators, what do you think are thrit mistakes?

User 05: That is easier than using the calculator because it gives input fields. It doesn’t let you mistype parenthesis like the mistakes that all the people do so often with the calculator. It has clear input fields for each of the things you are trying to find. It reduced mistakes because it also breaks down the variables you need to use.

User 04: I think it should be giving you a standard way of giving answers for chemical equations and giving you details of calculation. What is important is to giving a quick and convenient way of knowing the result. You can also learn and check your mistakes if you do it your calculation in old way. In the old way, you are calculating by hand and you do all the steps from mind. Maybe there are some mistakes when you do it in old way. After you enter reactants and products

> in this software, it will give you a right answer and the detail of how you should calculate this. So you can compare your manual calculation and steps; if you need to you can modify your calculations.

Does StoiCalc Lie?: StoiCalc is Reliable

We use cognitive artifacts as external aids to support our information processing. We generally rely on them because we think the results given by a cognitive artifact should be true. Basically we believe them as long as there was no mistaken input. Users explained that results given by *StoiCalc* are true and reliable, regardless of any poor or good design.

> **User 0:** I think it is kind of more like delegating the problem solving skills to the software but it definitely would save me a lot of time if I were using this on a regular basis. These are simple calculations but they do take a lot of time. It is just good to know that I can use this and save a lot of time with it as long as it seems fairly reliable.

> **User 03:** For molar mass, I think this is an automatic way to calculate without checking your book for a periodic table and element masses. In balance equation, you don't have to write each element. They are calculated in a different way than in most textbooks. All you have to do is enter reactants and products to the computer. It can solve in a computerized way and gives you all the coefficients, which is reliable result for me. I can trust that.

User 05: For the molar mass it just insures that I am going to get right calculation. The molar mass is not doing anything I couldn't do with a piece of paper; it is just quick and accurate.

User 05: For the balance equation I don't know if everybody going to take the same approach to learn how the computer does it. You might just rely on computer does the balancing equations for you. You don't have to look to the solutions page to get the answer you are looking for. That is just if you want to understand what you are doing. But it is certainly useful.

StoiCalc Does its Job: Effectiveness of StoiCalc :

In our modern society we dedicate lots of jobs to cognitive artifacts. We may think they are reliable but we also need to make sure that they are doing their jobs properly. The effectiveness of cognitive artifacts is very important. When they are asked about the effectiveness of *StoiCalc*, participants explained that *StoiCalc* is generally an effective tool to do the tasks it is assigned:

User 01: I think the "*Balance*"; "*Molar Mass*" and "*Solutions*" did the job very effectively, very easily and smoothly. "*Chemical Reactions*", once I knew what I have to do, it did very effectively. "*Conversions*" are the part that I was disappointed what the effectiveness on.

User 0: It definitely does its job. But, like I said, I have to work on the software to learn how to use. Normally, an intuitive interface would make more sense;

here I have to wait for the tool tips to show up. I think it defiantly will be improved. Otherwise it is effective as a tool.

User 03: I think it is quite effective when you solve relatively complex balancing equations.
What I was given for the problems are not complex but I think it could solve difficult reactions with 3, 4 reactants and 4,5 products.

Researcher: So what do you think about manual calculations vs. software?
User 04: Doing calculations by hand is very important, but if we already know how to calculate this manually it wont be necessary to calculate by hand every time. Using software is much better than the old way.

It is not Rocket Science: StoiCalc is easy to use.

Naturally users expect their artifacts to be easy to use. It is a natural result that when the artifact is easier to use, a user would likely use it more. When users were asked several times during Think aloud sessions about the ease of navigation and use of functions in *StoiCalc*, participants (except user 04) indicated that use of *StoiCalc* was fairly easy in general, especially once they figured out how to use it:

User 0: I thought like it was very user friendly. Last time I was looking to different function I wasn't actually using them, but it looks like it was apparent what you suppose to do when and where.

User 0: It was actually pretty easy. For someone who has chemistry background that knows the concepts it is nice to have a tool does it. It was easy for me once I had the video.

User 01: It is fairly easy. The molar mass is fairly straightforward and simple. The balancing equation, I just, I had a mistake using a zero instead of "O". I don't think that is specific to software. I think this is an issue I had over the years. But… once I figured out what I was doing incorrectly, it was easy to tell me exactly what I have expected to find out.

User01: I thought it is fairly easy. I made some comments where are some boxes to type in and where the answer is given, that might just be more users friendly. But navigating through the program and finding out like in the about tab, where to go for balance or molar mass, it was apparent what you need to do. For the basic functions I just don't have any questions about.

User 01: It is very easy to navigate around. In one question I start from wrong place because of not reading carefully but it was my own failure. I don't think that is a flaw in the design of the program. It is just I didn't read it [question] correctly.

User 02: It was very easy to calculate molar mass. The software did it for me and it explained each step in the process… no. Not each step. It didn't explain each step. But it did it for me. "*Balance*" was similarly easy. Although it helped to read the help page to see what the boxes mean. A little more complicated than

the "*Molar Mass*". Not difficult but "*Balance*" it is more complicated than the "*Molar Mass*".

User 03: The most parts are intuitive. There are little hiccups when you try to do something. It is intuitive put data and expects answer when push buttons. If you put a unit it doesn't work. I have to consult help pages, two or three times, to see what I have done wrong. But I haven't horribly screwed anything up.

User 03: Very easy. The only problem I had was the choice to include the mass for some reason. And when I went to the help page, I scrolled quickly to the step where I saw there is no gram here. I stay in the help page a little bit longer to make sure to see what is wrong. I figured that was just my mistake. It seems to me very easy to navigate after that.

User 05: The "*Molar Mass*" function was very easy to use. I knew there is no way to put subscripts so typing "*Chemical Reactions*" was pretty simple. It gave me a direct answer. For the "*Balance*", again it was not immediately apparent where or how I should be entering the data. But once I saw the help page and "*Chemical Reactions*" tab, which had labeled, I saw in there pink box is for inputting reactants and the larger green box is for inputting for products of reactions. So once I had figure out that, it was easy. It gave me good answer and good explanation when I click the balance equation button.

User 05: Very easy to navigate, you cannot get lost in sub menus. There is just menu at the top, has all the functions. You click on the one tab you like and it is right there for you.

Researcher: What about the navigation of help page.

User 05: It is equally easy. It tells you for each one.

What is the place of StoiCalc in Learning?

StoiCalc helps us to think. As described in the previous chapter, *StoiCalc* is an ease to use, reliable, and effective cognitive artifact that simplifies steps, overcomes limitation of calculating slow, and reduces errors in chemistry problems.

What is the purpose of *StoiCalc*? That is, is *StoiCalc* a chemist's tool or a learner's tool? What are the possible uses of *StoiCalc*? What is the possible place of *StoiCalc* in teaching and learning activities? This section presents answers to these questions according the analysis of qualitative data.

New possibilities with StoiCalc.

StoiCalc provides fundamental and important functions for different problems in chemistry, as a participant indicates within following words:

User 0: You know these options you have are very important. For example, "*Dimensional Analysis*" is extremely important because that lets you know if you are taking the right factors of things. I think functions here are fairly important. ["*About*" tab], the way things listed here they seems like they are whole bunch of very important tools…

Because of these different fundamental functions of *StoiCalc*, using *StoiCalc* may crate new possibilities to aid students in learning environments. There are number of

different ways to use *StoiCalc* for learning. As it is described with examples below, participants indicated that *StoiCalc* might help them, or some other possible students, as a primary or a supplementary tool for teaching and learning activities. As well, they indicated that *StoiCalc* might be helpful in chemistry laboratories.

In teaching and learning practices, *StoiCalc* could help students to freely discover the concepts of chemistry by discovering the ways for how to do different problem steps. It could help them to check their answers directly from *StoiCalc* after they try to do the problem steps initially by themselves (i.e., by "hand.") Therefore, *StoiCalc* could be very helpful for the students to realize problem steps, see the relationships and connections of these steps to chemistry concept and analyze the details of procedures in problem solving in a kind of exploring free fashion:

> **User 0:** What it can be also useful is using this as a teaching tool, if students learn chemistry they can fool around with different things like "*Molar Mass*", most importantly "*Balance*". It helps them to understand how do you balance the equations. ..

> **User 0:** I already know how to solve these problems, but I think this would be something very nice to give to students. For example, you can give it to freshmen chemistry students to let them see and play with the numbers. It gives you an idea about the chemistry. They can see, for example for a bigger organic molecule to burn, you need to have more O2 than for smaller ones. They can compare organic compounds. That can give students very good idea about the facts, like you need to have more O2 to burn benzene vs. just methane. You can also add a feature to

let students know how much energy needed or produced from the reaction, like exothermic and endothermic reactions in their nature.

User 0: I think the biggest advantage of having this software would be it gives you better handle on quantitative concepts of reactions and chemistry in general. I think every chemistry student would know certain reactants produce products, but how exactly do they interact, how much of one species will be needed with another can be understood by interacting with this software. So from that perspective it is really nice… I think this has a lot of promise.

User 01: Yeah, I think like it will be definitely useful for students , checking their work like learning how to do different tasks in chemistry. Uhm. Definitely they can just use the program to figure out, all the time they could be figure out on their own. But that could be definitely a good teaching tool to help them with checking stuff and making sure that their doing right.

User 02: … making students use the software could help them to realize the correct procedure and the steps involved. You can't find mass products without finding molar masses, so perhaps it will help students to realize the steps involved in these kind of problems.

StoiCalc may be used as a tool for checking in homework. When students need to check their homework, *StoiCalc* possibly can help them to realize the appropriate problem solving steps:

User 01: Checking homework, checking if they stuck on something maybe using that like a tutorial to see how problems are modeled. Because sometimes you see one problem in class but then something is a little bit different, a little bit a more complex of a problem. So the software enables you to see the different stuff necessary to work out a problem when you doing homework, doing different problems you may know how to approach that problem and how to set it up.

User 04 : . I think this one gives us detail of each step and how to calculate the result, so this can help us to analyze what you need to do in the whole way and which steps you have made a mistake. This software can help us analyze our own steps and check which steps we are wrong.

User05: Just for learning the algorithm, it is just a verification method for if you did the problem right and then you walk through the problem…
User 05: Just … well. The main purpose probably provides support for the people that are learning relationships, provide some resource that they can check their answers and resource for how the answers are found; but not in all functions.

StoiCalc may be used as tool for introducing problems and concepts in Chemistry. *StoiCalc* will be very helpful to help students to develop in initial understandings:

User 02: Definitely an instructional tool to help kids understand how to calculate molar mass or possibly how to calculate theoretical yield. I am not sure

it will come before or after the concepts are taught. I think it can be helpful for classroom for initial exposure to the subject….

User 02: The advantages of [*StoiCalc*] include an initial exposure to chemistry calculations. It seems to be going over all a tool for common calculations you have to accomplish or perform for a chemistry classroom.

User 02: I guess, this software influences my learning through to exposure through the concepts I never heard before like a conservations table. I looked it up online, I found in the program that I never seen. So that encouraged me too look something up that I never experienced before. I suppose that would be more common for the students taking chemistry for the first time.

User 05: They all seem like wide variety of functions you can use here that could be useful for any introduction to chemistry course.

Finally *StoiCalc* may introduce new and alternative methods in problem solving chemistry:

User 02: I said these two sections of software [matrix] really interest me. But I don't know if every student will be as keen on really understanding what the heck this means. To me, at a classroom setting, high school, and middle school maybe, it seems that the students will use software for the answer and care little about the explanations. It is nice to have. I think teacher will need to make sure they understand what is going on.

StoiCalc may be used as a tool in laboratory work situations. *StoiCalc* helps technicians obtain answers for variety of problems very quickly when they work in a laboratory, and it also and provides common functions and pre-defined settings for general laboratory practices:

> **User 0:** If you are a guy working in a lab you can use it right away. If you want to study chemical reactions or analyze your data that is something is useful…

> **User 0:** I am not sure which one would be more important for the purpose but given what you have here, I think it is more important as a teaching tool, can be used in the labs also, especially when you have yields like here [“*Yields*” tab] and making solutions. This is a very important thing, because we very often making stock solutions and then we dilute them when we actually use it. So from a chemist's point of view who is working in the lab, the “*Molar Mass*”, “*Balance*”, and “*Solution*”s are very important for your experiments. For “*Conversions*” when you are reading papers, if you are not familiar with a unit, you can convert them. “*Yields*” will be important to see how to analyze your data you got, I am assuming.

> **User 0:** [at “*Solutions*“ tab, user discovering concentrated reagents tab, which provides a list of frequently used solutions]…Hey, that is nice, you can actually make a solution that solutes it self. These two are something we use very often in the lab practice...

User 0: I think as a tool that will be really nice for someone learning chemistry especially for someone getting the idea of starting working on lab. I remember when I was starting in a chemistry lab. I would be literally terrified of making solutions and epically buffers. I wish I had the software like this, life would be much easier.

User 01: With the preparing solutions, it displays the recipe if you are given solutions to prepare. It tells you everything you need and how to prepare. That would be beneficial as far as a lab would go.

User 05: If you are in the lab. With a laptop, you may want to know how much of the compound that you need to put in. This is going to insure that you are not going to screw up with a calculator error. This will give you right equation. If you will be in the lab, this will be useful. I don't want students doing homework with this necessarily. But when you need a quick calculation, this is useful.

User 05: You are just getting your answers for your worksheet that might particularly helpful. But it is super helpful for learning if you do a lab calculation and just wanted to check your answer. If you know the process already, and you don't want to have to do anymore because it is tedious, it is very useful.

User 05: If you are in the lab, you should have some background about the relations. This would be super useful in the lab. Inputting things to calculate. There is no risk of making calculator errors. This would be very useful , I would think, if you are working on a lab.

Another way to use *StoiCalc* for laboratory may be in preparing students before going into teaching laboratories:

> **User 01:** I have a choice to display recipe [click]. [Read aloud recipe].
> Ok, this would work if I were given a lab and I was told that I needed to prepare this solution and I wasn't sure how to do it; this would tell me, step by step, what I needed to do. That is good. Sometimes student doesn't know you just need to add 10 g of what ever your compound it is saying and bring up to 400 mL.
>
> **Researcher:** What do you think about the option of "*Display Recipe*" ?
> **User 01:** Just giving the result would be fine if I am working in a worksheet of problems, I wouldn't necessarily need to know exactly how to prepare it . But if I were using this for a preparation, for a lab like doing a part of a worksheet, I will give this and students will go to use that before going to their lab. And it is going to tell them exactly how they need to prepare solutions. That will be the difference for me and where I would see the different uses depending upon where I would be.

One user adds that *StoiCalc* could be more helpful in laboratory situations with improvements and additional functions added to it:

> **User 0:** I would actually use it if I am making simple solutions, yes, I would definitely use pure solutes.
> Normally I do it using a calculator. Only thing in user end point of view, because we have to maintain a record of what we are doing, I kind of wishing we can

> import -export a file of our calculations or printed out because scientist point of view, you need to save or preserve what you did. Sometimes, if there is mistake, you need to go back and check. Record keeping is extremely important in the lab. Doing a right thing again and again or keeping track if we do it wrong. That is something I would appreciate if we could add it, the option of print out or saving as a file. Also you have pure solutes but in the chemistry lab, it is very common to use buffers, which has more than two or three salts in it. If you have this in the future versions, as pure solutes for current version. That would be definitely a plus for the software.

Old Mind Sets:

Changing teaching practices may make students be able to use *StoiCalc* as a professional tool in their learning environment. However, analysis of interactions shows that there should be a change in teaching-learning activities in order to incorporate the use of *StoiCalc*. The successful implementation *StoiCalc* in learning depends on a change in mind sets of teachers and learners who tend to embrace traditional teaching and learning approaches:

> **User 02:** It really depends how a teacher uses it. I think that, if I use this in the classroom, I could make it an effective tool. Especially students learning dimensional analysis, it would be a good tutorial throughout the process. It could be something helping students understanding exactly when they do on their own. So it could be effective. But it could be also detrimental, but it really depends on the teacher

Without meaningful learning, *StoiCalc* itself doesn't improve any skills. In order to fully understand the chemistry concepts in *StoiCalc*, students should have prior knowledge about the basics of problem solving steps, algorithms, and related mathematics. There is a question of how much a student needs to know about these internal steps in order to make meaning out of any end results. In order to make meaning from the end results, do we have to understand all the middle steps and algorithms necessary to get those end results? Traditional teaching and learning approaches emphasize knowing problem solving steps and being able to perform these steps in pen-and-paper (and usually calculators) in order to fully understand chemistry concepts. Traditional views do not support the idea of delegating tedious calculation work to computers or even sometimes calculators.

Similarly, according to users' points of view, students need to know (or at least see) these steps in order to understand the results and to make meaning out of them:

> **Researcher:** If you think you just start learning these concepts in chemistry, would you prefer to use software or would you prefer traditional ways?
> **User 04:** If I don't know the meaning of these basic chemistry topics, I would rather to use traditional way because it gives us the basics.

> **User 01:** I think when it could be valuable as it would show the math on how to set up the equation on your own. Because with the balance and molar mass functions with this program I used before, it does show you that. I think if you are using that as a teaching tool to learn how to do something to make sure you are doing something correctly, to check on what you are doing. It is valuable to teach exactly how it came up with the missing number. Otherwise when they are

not using the program they are not going to know how to set that up. I do (know), but I didn't have to and it wasn't showing me how to do that either. If I were using that to work on a homework assignment, but I was expected to show my work, this tool would just give me an answer. If I didn't already know how to specifically set that up I wouldn't be able to do that. And it is more needed in more complex calculations like in solutions with many steps than it is in molar mass where there are fewer steps. I think that would be something highly valuable to add into that program.

User 01: I think it could be very useful tool in the classroom but it would help to figure out how to do different problems, help you to check your answers. If there are some additions to help to figure out the math and begin, it will more efficient. I know it is a big hang up for a lot of students, so that will significantly will improve what the benefits of the program are. I think it is a cool program to help in different problems and different aspects of chemistry.

User 05: For students learning, it seems it plays a support role than a direct teaching role…
You use this to confirm your answers and do calculations, but not as a primary method to learn these algorithms.

Because of not performing math for the steps by themselves, users thought that they didn't improve their problem solving skills with *StoiCalc*. They explained that *StoiCalc* provided a quick, automatic, easy, and simplified way of (see above sections)

for finding results but it didn’t improve their problem solving skills a lot. So they may prefer to do the pen-and-paper calculation by themselves to learn all the middle steps:

> **User 03:** [using *StoiCalc*] I think you don't have to remember all the formulas, all the molar mass for each element. You don't have to calculate the mole for the molar masses.
>
> I think learning process for the chemistry course could not be ignored. This software is just a tool. You can check back with your paper calculations to just see. If you trust this software you can directly what you need. You can ignore the paper calculation. Because you don't have to know all the details in the problem solving here what you got here is a direct answer. You don't have to learn some mathematical calculations in chemistry.
>
> I think I don't learn any chemistry just finding the results.
>
> **Researcher:** What do you think you need to do to learn chemistry?
>
> **User 03:** I think in chemistry all the things should be written in detail. For example, you have to remember the periodic elements table. You should remember how much is the molar mass for the elements and how to calculate the formula. For example, H2O if you don't know chemistry you may write H2O2 that is another material. So the basic knowledge for chemistry you need to do in paper, you have to read materials, documents, books. But solving problem is another thing. This software makes your calculation procedure simplified, only if you know the basics of chemistry.

User 04: I think disadvantages, if they don't use this software, then they need to do lot of mathematics calculation by themselves. I don't know if this is good or not for them. Because they may lose their math skills. If many students use that, they won't learn how to calculate these to find the results without any electronic devices. They may not learn how to do that in computer because you just give the numbers to it. I mean, it is not like pen and pencil.

Researcher: Would you prefer to use calculator or this program?

User 05 : If I were preparing a lot of stock solutions, I might use this program, but if I was trying to learn how to create the diluting solution, I want to go with the algebra first. I want to be able to do the math on paper first.

Researcher: If the software shows the math procedure in the display, will your answer change?

User 05: Maybe not initially, but I will be far more apt in to use it once they have seen the algorithm, done it on paper themselves, then they can use this to confirm their answers. I wouldn't want them to rely on this for applying all stock solutions recipe.

User 05: I don't know if it is going to help my problem solving skills at all. It will allow me check my answers, certainly if I was looking to do it on paper and want to be sure the method is correct. It doesn't give you a protocol to use to find the answer. It spits the answer out once you select your target variable from the drop down menu.

Researcher: Do you think it makes any difference to use the software?

User 05: It will confirm my answer but it wouldn't change how I did it on paper.

User 05: It is just sometime you are inputting data in a black box and it is spitting something out. Without understanding the reasoning or the algorithm being used, you are not really learning anything.

User 01: I am not sure how it would improve my problem solving skills since the computer is doing the problem solving for me. I think it would be definitely beneficial to check what I have done and make sure you have instant feedback for what you have done, if it is right or not. But I wouldn't rely on this all the time because I wouldn't be learning on my own how to do. I think it is a good example method to check the work you already done but if you just putting the equations into the software I think you would be learning these concepts. For my personal problem solving I don't see it is really doing a top of that.

User 0: This is something more of a personal choice. I think if you want to learn how to solve problems, you have to sit down and calculate with pen and pencil. This could be used to verify what we calculate by ourselves to see if they are correct.

User 02: I don't know it will improve my problem solving skills for preparing solutions. As a matter of fact, I am not sure whether to use this program in a teacher setting before I teach them calculating on their own.

Researcher: What makes you think that?

User 02: I mean, diluting stock solution isn't very difficult. You use dimensional analysis to even up your units and multiplied two numbers and divide them by the other and you get your answer. But what really helpful about this program isn't so much in find mass or find dilute volume but the recipe. I

mean this one is little more end up as far as the math involved. It is just a pretty simple calculation. I don't think that improves my ability to do that calculation

Users thought that *StoiCalc* may make students dependent upon it because it just does every calculation by itself automatically. Students may not want to learn all the calculation steps because *StoiCalc* does the calculations for them. One user addressed that one the major drawback of *StoiCalc* is to become too dependent upon it:

User 02: [at "*About*" tab] Actually I just want to go through all. .. [Move over the tabs, go back to "*Import Eq*." button]. I can import some ….. Mmm.. [read tool tip for import equation.].. [Mouse over back to Tabs, click "*Conversions*" , mouse over several buttons and reads labels.] electrolysis .. Which is excellent because I had a terrible time with the electrolysis.

[Reads title of main buttons, liquid , mass / weights].. I don't know this tool make students more dependent on calculators.

[Laughing.. .] It seems it takes a lot of work out of it .

…

User 02: I know this box shows you how it is calculated [showing molar mass displayed at the field for results] but I don't know how many students will be encouraged to learn how it is calculated or to understand.

User 02: The drawbacks, I guess, they will be easy to avoid but after a while I really wouldn't want my students using this over much. It is not difficult to this with pen and paper and calculator. It is a good way to introduce the concepts and show them the answers that makes sense. For balancing equations it is all-good.

The major drawback would be I guess dependence and this is really up to the teacher.

User 01: The one thing I can see, if students are using this all the time they might not be as familiar as with molar mass or element mass. They might not become familiar with that because the software is just doing for them.

User 05: For the balance equation, I don't know if everybody going to take the same approach to learn how the computer does it. You might just rely on computer does the balancing equations for you. You don't have to look to the solutions page to get the answer you are looking for. That is just if you want to understand what you are doing. But it is certainly useful.

User 01: … I mean, when I would test students I would want to know what they know and what they know how to do. It would be really hard for me to say, doing in this program, "do they just enter it just in accidently or do they actually know what they are doing and why they are doing it?"

Researcher: Would you prefer to use this software?

User 01: I think there are places for them to use it but I wouldn't let them rely on it because I don't feel like t will be always available for them, like what if my school doesn't have the money to buy computers.

I am not sure if they will have the software later, I don't want them to say when they go out of college "When I was learning this I always relying using the software to help me through to these kind of problems but so I don't know how to do it on my own."

Finally, according to users, *StoiCalc* would be impossible to use during tests and examinations:

> **Researcher:** if you use that software for teaching, do you think it will improve your teaching or your students' learning?
>
> **User 05 :** If it was a high school class, I don't know how useful it would be. I am not going to use this on the test ever. The reactions they will be doing in the class aren't going to be super complex ones that balancing is difficult…

> **User 04:** I think both of them are important. Software is more efficient and saves us a lot of time, but the traditional way is also important. If we have no computer in an exam, we also need to calculate these problems by hand. But for most of the time, if we know how to calculate in the traditional way we can use this software for more efficiency.

Modern tools for modern Society:

Modern humans use cognitive artifacts to construct knowledge in modern societies. In teaching and learning practices everyday, it is becoming more and more important (see literature) to incorporate these artifacts in teaching and learning practice:

> **Researcher:** Do you like the software?
>
> **User 04:** Yeah I think so, it is necessary I think.
>
> **Researcher:** What do you mean by necessary?

User 04: Cause in modern society if we always waste time to calculate in old traditional way it is not efficient. Because all those steps are just same, if we know how to do that so we need to find a more efficient way like this software.

In chemistry teaching and learning situations, *StoiCalc* becomes very important to integrate into instruction. Users explained that they would appreciate the implementation of *StoiCalc* in chemistry teaching and learning practices:

User 02: I really like it. I think it is really impressive as far as specific recipe for solutions. I think that is impressive. Recognizing formulas with subscripts ["*Balance*"] with different elements. I think that I definitely should be incorporated it in a chemistry classroom.

User 0: Well for me if there is more complex thing that I don't know I would definitely use to learn from it or use it in regular basis. This level, I would definitely recommend it to younger students that are learning chemistry.

User 05: If you just don't want to have to go find a periodic table and get some masses and conversions, it seems pretty useful and pretty quick doing that for you. It helps you to avoid the calculator; it does it for you..

CHAPTER V

Discussion and Conclusion

StoiCalc simplifies problem solving steps, overcomes limitations of calculating slowly, and reduces errors in a reliable, effective, and easy to use manner. This nature of *StoiCalc* matches the definition of cognitive artifacts. Because of this nature, *StoiCalc* could be very helpful to use in teaching and learning activities.

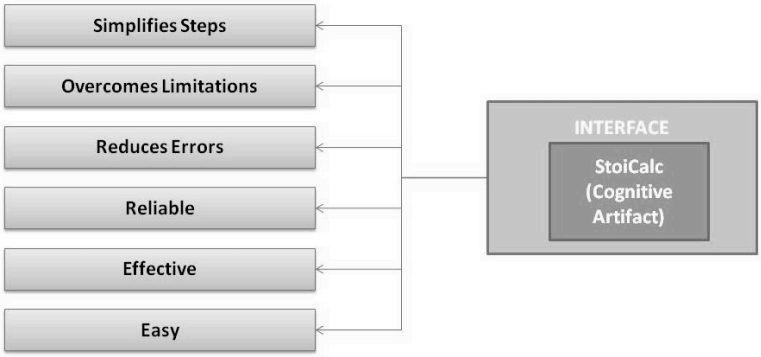

Figure 5.1 *StoiCalc* as Cognitive Artifact

On the other hand, interestingly, most users don't want to rely on *StoiCalc* all the time, because they think they cannot learn how to calculate these problems without doing them by themselves. So they mostly think that *StoiCalc* is a kind of calculator tool that makes calculations easier and faster in a reliable, easy, and efficient way. This mind set of users lead them to think that *StoiCalc* could only be used to show quick results in a laboratory or introductory chemistry course, or for checking their answer when they do homework. On the other hand, they think exposure to chemistry contents with *StoiCalc* would be helpful for an initial exploration of chemistry. They think *StoiCalc* could be

helpful to show students relationships between concepts, to make them aware of problem solving steps, and to lead them in problem solving. Finally, users think they cannot use *StoiCalc* during exams so they need to learn how to do the same calculations with pen and paper methods.

This mind set of continuing traditional teaching – learning activities brings up a questions of why we use tools and why do we hesitate to delegate work to artifacts before we get a full understanding of these works first without tools. *StoiCalc* may be more efficient than the human mind for calculating accurately and quickly. It will be very useful in decision making processes. However, users want to check the results and be in control of making these steps by themselves. They don't want to use *StoiCalc* all the time. This also brings the question of what is important to know and what is not. For example, should we be able to make decisions by interpreting the results, be able to obtain these results before any decision making, or should we be able to do both? Is it sufficient to make decision making process without knowing internal calculation steps? What is important in chemistry, making calculations, or understanding the concepts related to the results that are given after calculation? Why do we have to invest time and energy to learn these calculations, especially if reaching results is not very important, but the decision making is? Why do we need to check students' understanding or performance by calculating these on paper? Why don't we like to depend on modern cognitive artifacts, like computers? Even if there is possibility to bring laptops into classrooms, why we don't let students use them during examinations? Is this just because of security, or is it a need for controlling everything?

These questions are out of scope of this study. However, we could investigate the results in previous chapter and give some models to understand implementation of cognitive artifacts like *StoiCalc* in teaching and learning.

Regardless of possible uses of *StoiCalc* in teaching – learning practice, users indicated that *StoiCalc*, as a cognitive artifact, simplifies steps for them because they don't need to calculate much. *StoiCalc*'s computational powers overcome the limitations of mind to make calculations quickly and accurately. *StoiCalc* calculations are error free. It provides schemes for problem solving steps to lead users in the procedure that also reduces error. Also *StoiCalc* is reliable because it gives results consistently. *StoiCalc* does its job effectively and is easy to use, especially when users understand how to use it.

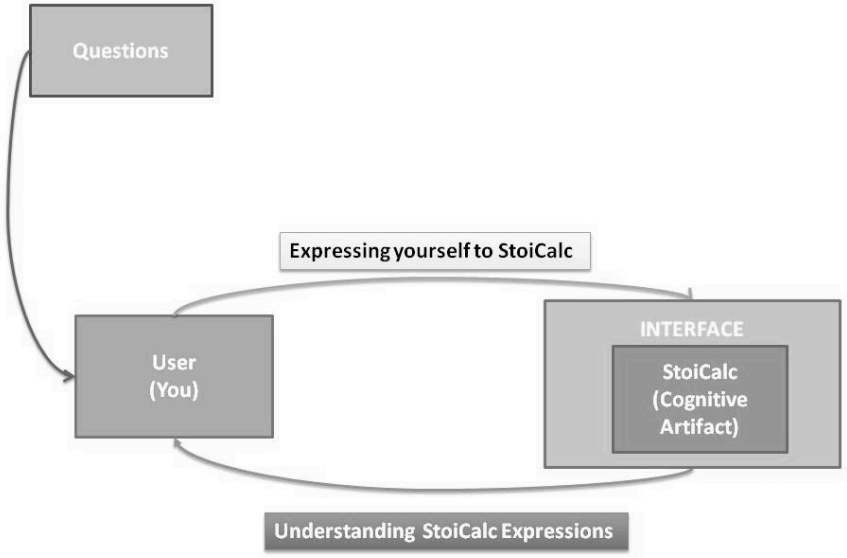

Figure 5.2 Interactions between users and questions, users and interface.

When we engage thinking processes, our minds need directions. When we use any cognitive artifact, we seek for pathways or schemes in the design that may lead our

mind. As designers, when we implement design of cognitive artifacts, especially in teaching and learning practices, we need to make sure we have a design that correctly leads users' minds. We should make sure users find a starting point in these schemes, and verify that they follow schemes correctly to reach end results. Also, we need to make sure that they understand how to express themselves on the interface as well as how to understand interface expressions. Moreover, we need to show them what is going on in the internal process of the artifact. The interactions between users and questions, and users and the interface are illustrated in figure 5.2 (above). The cognitive artifact interface may be the only gateway where users directly interact with it. In order to have a successful interaction between users and the cognitive artifact, interface design should lead users' minds to express them to cognitive artifact correctly. As well, the interface should be good enough to lead them to an understanding of the expressions used by the cognitive artifact'.

When executing tasks in cognitive artifacts, users' minds need direction. Figure 5.3 shows how their minds possibly could be directed in the design. First, users need a starting point to see where to start. In cognitive artifact, the design itself gives clues for starting points. Sometimes the questions give some clues about where to start. After they find their starting point, the cognitive artifact interface should lead users to show how they express themselves to it. That is, the interface should lead them toward appropriate data entry.

When users are expressing themselves, they need to know how to format their expressions. The interface should explain to users how to format these expressions directly. Also, the cognitive artifact's interface should have a method to check and

validate these expressions in order to have correct calculations. Sometimes, cognitive artifact interface may fail to lead users mind intuitively finding the correct step in the scheme; so users have to consult manuals and see available help options.

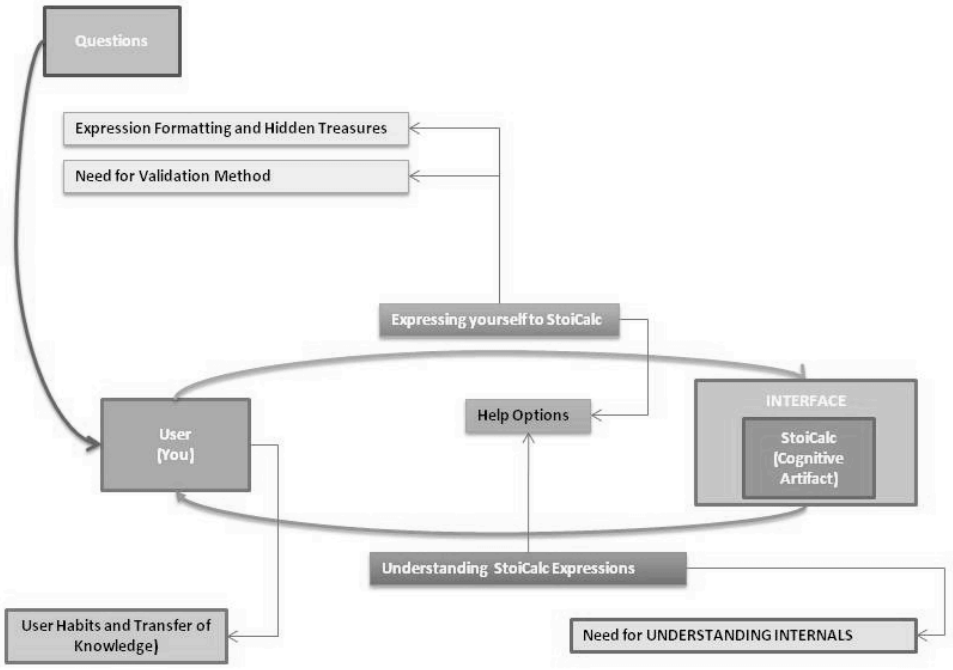

Figure 5.3 How the Mind Directed in *StoiCalc* Design.

After users express themselves to the cognitive artifact, that artifact itself (many times independently from the interface) does its job and calculates the results according to expressions given by the users. Then the interface takes over again and expresses the cognitive artifact and its results back to users. These expressions are interpreted by the users; sometimes users need more clues and directions to understand the cognitive artifact's internal processes, such as the arithmetic involved to reach conclusions.

A design problem or other issues in the scheme may cause interuptions in successful task execution. Interaction in the flow of steps because of poor design leads minds inappropriately. Users may go to try and see a procedure, to consult help, or simply to stop engaging the task. They may think they had something wrong, like inputting data incorrectly or following an incorrect sequence of steps. Sometimes they may find some explanations of steps in cognitive artifact so they can analyze and see the current situations.

Sometimes a cognitive artifact may become a total “black box“ for users. Moreover, these interactions may end with confusion and frustration. If there is no interruption in executing steps, users get direct results from cognitive artifacts. When users have schemes of problem solving as a step by step procedure in the design and when they understand what cognitive artifact express to them, they feel more comfortable and in control.

Finally, users tend to transfer their previous habits and knowledge when they interact with other cognitive artifacts. Designers should be aware of these possibilities and they should lead users in the transitions processes. In addition, designers can match some users’ previous experiences in their current design to have an easy adaptation.

Parallel to the illustration in figure 5.3 above, when using *StoiCalc*, users seek ways to express themselves to *StoiCalc* after they define their starting point. They express themselves by inputting data according to acceptable formats. Also, as part of entering data, users seek places to enter data. They mainly focus on entering correct variables into appropriate fields. After that, they start interpreting the meanings on *StoiCalc*'s interface in order to understand how it works or how it expresses itself to users. At the same time,

they start thinking about the schemes for steps of executions in *StoiCalc* to solve problems. When *StoiCalc* displays results, users engage in another thinking process to interpret those results. In ideal cases, if they express themselves properly and the design leads them to results with no interruptions, they try to understand the results by interpreting them. They want to have a checking method that may be showing how the *StoiCalc* obtained its results. When there is an explanation on display, they read and check these to see whether *StoiCalc* calculations seem correct. If there is no explanation, they start looking for one or they start to check them in their minds. When they finish this process of thinking, they reach the end and complete the tasks. After a while, when they understand the internal algorithms, they trust the *StoiCalc* and give up checking the results.

As explained above, cognitive artifact's interface may be seen as a kind of map of its internal world. As when reading maps, users need a couple of reference points, like where are they standing right now, what directions are available, and a possible route to go to these available directions. Cognitive artifacts should indicate the standing point, routes, and available options very clearly. Also, help documentation (like an internal map) should show the users their location immediately and show them the directions.

In problem solving steps, the cognitive artifact should represent its internal states as well as try to understand users' expressions. The language between user and cognitive artifact, which is the interface in common, should be simple enough to ensure communication and interaction of both parties.

Intuitively. users should know how to express themselves as well as how to understand cognitive artifacts' expressions or outputs. In this process, a designer should

help users to understand the cognitive artifact's language by providing clear directions both in the cognitive artifact design itself and help manuals.

While designing a cognitive artifact like *StoiCalc*, designers should attempt to have users realize that the cognitive artifact has a special language or scheme consisting of a set of rules and steps to follow. Users may recognize these schemes when they read "helps." Some users may not look to a help page in the first place, however. So having a help page, when that the help page gives explanations and examples, may not help users initially. Moreover, some of the users may be confused because of the poor design of the help page. Some of them may still make mistakes even though they did look to the help page, perhaps just a few moments earlier.

If there is a problem of remembering the steps, the cognitive artifact itself should show them what steps are necessary to input, what steps are followed when clicking buttons, and what is the meaning of the result that cognitive artifact displays at the end of calculation. Cognitive artifacts should lead the way in the steps, especially if there is a clear algorithm for reaching solutions. If there are possible alternatives and fuzzy logic behind the problem solving steps, the cognitive artifact should at least show vey clear ways making and initiating process. The cognitive artifact itself may also have a template or step-by-step directions to lead users' minds and to walk through then through the processes from the starting point to the end results.

Cognitive artifact should explain the results and the steps that have been taken during the problem solving process. It is critical that users have available deep explanations rather than just showing the end results. Users may need to know every step behind each function that is connected to a button (except common buttons which are not

really directly related into the problem solving process). Users want to double check the results and steps in order to understand what is going on in the internal process of the software. The artifact itself should have a mechanism to show each step where users can understand the relationships between each function connected to the buttons. The artifact itself can also describe results, the buttons, and their functions separately in a fashion of screen walk through movie to explaining the processes of problem solving. In the design of an online learning course that may be aimed at teaching students to use a cognitive artifact, this step-by-step screen walk through methodology should embedded directly into the cognitive artifact.

In conclusion, cognitive artifacts lead users' minds in decision making and problem solving processes, and the design of the cognitive artifact affects these processes. The design should ensure that users express themselves correctly to the cognitive artifact's interface, and they should understand the cognitive artifact's expressions or outputs correctly. When there flawless design, users generally think that cognitive artifacts help them, simplify steps for them, overcome the limitations of their mind for doing tasks quickly and accurately, and reduce errors in a reliable, effective and easy to use way.

More than cognitive artifacts' success in design, successful implementation of cognitive artifacts into teaching –learning practices depends on users being willing to dedicate tasks to cognitive artifacts. Users may like the idea of benefiting from cognitive artifacts. Because of having a mindset to follow traditional ideas in teaching and learning, however, they may tend to limit the usage. They may think that dedicating a task to a cognitive artifact makes them dependent on that cognitive artifact, and they think they

may not learn how to do the tasks by themselves. They are more likely willing to use cognitive artifacts after they can do the task by themselves. How important are these tasks and the need for dedicating them to cognitive artifacts are the questions that may depend on users' judgment. These questions are beyond the scope of this dissertation, and can serve as a future research topic.

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APPENDIX A

IRB Consent Forms

UNIVERSITY OF Nebraska Lincoln

COLLEGE OF EDUCATION AND HUMAN SCIENCES
Department of Teaching, Learning and Teacher Education

Informed Consent Form

Title of Research: COGNITIVE ARTIFACTS (MoleCalc).
Primary Investigator: Ilker Yengin

Before agreeing to participate in this research study, it is important that you read the following explanation of this study. This statement describes the purpose, procedures, benefits, risks, discomforts, and precautions of the program. Also described are the alternative procedures available to you, as well as your right to withdraw from the study at any time.

Explanation of Procedures

You are being asked to participate in the research project to investigate the issues related to the design of an online course aimed at teaching students to use a cognitive artifact within the context of "traditional" learning content. How these cognitive artifacts contribute to the students thinking and learning will be studied in terms of students' interactions and attitudes. Cognitive artifacts are devices that humans interact with to receive and/or manipulate information in order to engage in a thinking process. *MoleCalc software* is a cognitive artifact because it utilizes established chemical concepts to apply a series of rules sequentially that are challenging for most high school and beginning college chemistry students.

We are asking all the prospective participants to attend a pretest session in order to be considered as a candidate participant. Candidates will be called to participate a 15 minutes pretest session where they need to perform a small demonstration think aloud session. Participants will be introduced about how to perform think aloud before the demonstration. In addition, participants will be asked to fill out a short demographic data form (1 page) before they start pretest. This small think aloud session will help researchers for assessing candidates' ability to express their thinking, attitudes, and reactions to any online software. All the candidates joining to this pretest sessions will be paid $5. After the pretest session, a small number of (five) pre-test participants will be selected for a more in-depth session. Researchers will announce the selected participants and contact them through e-mail.

All the selected participators will be asked to join in the study that a series of three think aloud protocol and follow up interviews. All three sessions start with a think aloud session and ends with a follow up interview.

In think aloud approaches, you will be asked to talk about your thoughts, reactions, and opinions while interacting with a cognitive artifact which is a software called MoleCalc. Think

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aloud involves you thinking aloud as you are performing a set of specified tasks. You will be are asked to say whatever you are looking at, thinking, doing, and feeling, as you go about your task. Also you will be asked questions about your perceptions, first impressions, initial reactions and thoughts about the MoleCalc software. This enables researcher to see first-hand the process of task completion. Researcher will take field notes while talking with the participants.
While you are using the MoleCalc, your interactions and movements within the software (mostly mouse actions) will be captured into a video file using screen recording software. Also your think aloud session will be audio taped and transcribed. Audiotapes will be distorted digitally to keep your privacy.

After each think aloud protocol there will be a short follow up interview. Interviews will involve questions about your thoughts about the MoleCalc software. The interviews will be audiotaped by the researcher and later transcribed for the purpose of data analysis. Audiotapes will be distorted digitally to keep your privacy. The interviews will be conducted at a setting that is mutually agreeable to the participant and the researcher.

Duration:
Phase 1 (15 min in total): Pretest session will take 15 minutes.
Phase 2: (each session will take 1 hour, 3 hours in total for all sessions)
Each session is consists of think aloud protocol and a follow up interview. There will be 3 different sessions.
The think aloud protocols for each individual will be between 30 – 45 minutes in average over a period of one to three weeks. There will be 3 different think aloud protocols.
Follow up interviews will last for approximately 10 – 20 minutes each over a period of one to three weeks. There will be 3 different follow up interviews.

Place: Each of your think aloud sessions and interviews will be in room 123 A, Henzlik Hall, UNL City Campus.

Risks and Discomforts:
You will not be at physical or psychological risk and should experience no discomfort resulting from the research procedures.

Monetary Compensation:
By participating this research study you will be paid a compensation of $5 for participating pretest session and $ 15 for participating for each sessions (including both think aloud and follow up interview) and an extra $15 if you participate all three sessions (pretest is not counted as a session). If you participate pretest and all 3 think aloud sessions, in total you will receive $65. Also when you participate all 3 think aloud sessions, you will receive a free copy of MoleCal software, which is distributed without a cost as open software. MoleCalc software runs on Windows XP, Vista, 7 and MAC OSX platforms.

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Benefits:
There are no direct benefits by participating in this study. This research is expected to help instructional designers, policy makers, and school administrators understand the value of using cognitive artifacts in learning systems.

Alternative Procedures:
If a person chooses not to participate, an alternative procedure is not necessary.

Confidentiality:
All information gathered from the study will remain confidential. Your identity as a participant will not be disclosed to any unauthorized persons; only the researchers and UNL IRB will have access to the research materials, which will be kept in a locked draw. All the collected data (audio data will be distorted digitally) will be secured using digital 512 k password encryption and kept in a DVD stored in a locked place. There wont be any copy of the data in another place. Any references to your identity that would compromise your anonymity will be removed or disguised prior to the preparation of the research reports and publications. There wont be any third party transcriptionist just the researcher himself will transcribe the data. Audiotapes will be will be destroyed or erased at the completion of the study. Your name and last name will not be used in the transcripts of the recording.

Withdrawal Without Prejudice:
Participation in this study is voluntary; refusal to participate will involve no penalty. Each participant is free to withdraw consent and discontinue participation in this project at any time without prejudice from this institution. You are free to decide not to participate in this study. You can also withdraw at any time without harming your relationship with the researchers or the University of Nebraska-Lincoln.

Costs and/or Payments to Subject for Participation in Research:
There will be no costs for participating in the research.

Age Restrictions: You should be at least 19 years old to participate.

Questions:
Any questions concerning the research project participants can e-mail ***Dr. David Brooks*** (faculty advisor for this project) at dbrooks@unlserve.unl.edu , or call him at (402) 472 2018 or e-mail primary investigator ***Ilker Yengin*** at ilkyen@gmail.com, or call him at (402) 484 1094. Questions regarding rights as a person in this research project should be directed, ***UNL Institutional Review Board***, at irb@unl.edu , (402) 472 6965.

Agreement:
This agreement states that you have received a copy of this informed consent. Your signature

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Department of Teaching, Learning and Teacher Education

IRB# 20110411632EP
Date Approved: 04/05/2011
Valid Until: 04/04/2012

below indicates that you agree to participate in this study.

Signature of Subject Date:_____

_____

Subject name (printed)

_____

Signature of Researcher Date:_____

_____

118 Henzlik Hall / P.O. Box 880355 / Lincoln, NE 68588-0355 / (402) 472-2231 / FAX (402) 472-2837

APPENDIX B

Demographic Information Form

Name:

Last Name:

Age:

Gender:

- Male
- Female

Major:

1. I am experienced in using any kind of regular web site.
   - Strongly agree
   - Agree
   - Neutral
   - Disagree
   - Strongly disagree

2. I am experienced with using an online learning system (e.g., *BlackBoard*).
   - Strongly agree
   - Agree
   - Neutral
   - Disagree
   - Strongly disagree

3. I am experienced in balancing chemical equations.
   - Strongly agree
   - Agree
   - Neutral
   - Disagree
   - Strongly disagree

4. Please indicate names of chemistry courses you have taken.

(If checked, year and your estimate of your recall – high, medium, low, or little.)

Taken	Name	Year	High	Medium	Low	Little
☐	**General Chemistry 1**		☐	☐	☐	☐
☐	**General Chemistry 2**		☐	☐	☐	☐
☐	**Organic Chemistry 1**		☐	☐	☐	☐
☐	**Organic Chemistry 2**		☐	☐	☐	☐
☐	**Analytical Chemistry**		☐	☐	☐	☐
☐	**Inorganic Chemistry**		☐	☐	☐	☐
☐	**Biohemistry 1**		☐	☐	☐	☐
☐	**Biohemistry 2**		☐	☐	☐	☐
☐	**Physical Chemistry 1**		☐	☐	☐	☐
☐	**Physical Chemistry 2**		☐	☐	☐	☐
☐	**Physics 1**		☐	☐	☐	☐
☐	**Physics 2**		☐	☐	☐	☐
☐	**Calculus 1**		☐	☐	☐	☐
☐	**Calculus 2**		☐	☐	☐	☐
☐	**Calculus 3**		☐	☐	☐	☐
☐	**Any computer Science**		☐	☐	☐	☐

APPENDIX C

Think Aloud and Follow up Interview Protocols

Think Aloud and Follow up Interview Protocols Outline:

1.Screening (15 Min.):

Candidates who will respond to invitation e-mails will be invited to participate a 15-minute pretest session where they need to perform a small think aloud session. Researcher will briefly describe think aloud session and expectations from prospective participants. This small think aloud session will help for assessing candidates' ability to express their thinking, attitudes, and reactions to any online cognitive artifact.

Screening arrangements:

- Demonstrate Think Aloud Protocol to Participants.
- Introduction to the session (2 minutes)

Discuss:

- Importance of their involvement in the study.
- Moderator's role.
- Room configuration, recording systems and participants' privacy
- The protocol for the rest of the session.

2. Think Aloud Session 1,2,3 and Follow-up Interviews (30 minutes – 45 min):

Participants will start executing the tasks according to think aloud protocol scripts.

Follow up Interviews (10 – 20 minutes):

- Ask to collect user thoughts and other qualitative data.
- Follow up on any particular problems that came up for the participant.

Think Aloud and Follow up Interview Protocols Scripts:

1.Screening:

Task:

Researcher will ask participants to click *StoiCalc* button.

>Please click to the *StoiCalc* button.

Remember, at this step, you are not required to learn the course content on chemistry.

In *StoiCalc*, you can click on anything you like.

Suppose that your teacher wants you to discover the available options in *StoiCalc* by just exploring around. Please examine the page and describe the options you see.

Please give me your initial reactions to this page. Feel free to explore this page as you normally would explore any other webpage. Please remember to think out loud about why you're clicking on things and what your thoughts are. After you click on anything, do you find what you expected to see? Tell me about the page you are looking at. What options are available to you?

- If participant uses jump links: What happened when you clicked on [ITEM]? Is this what you expected to happen, why or why not?

SESSION 1:

Task 1.1.

Researcher will ask participants to click *StoiCalc* HELP button.

>Please click to the *StoiCalc* HELP button.

Remember, at this step, you are not required to learn the course content on chemistry.

In *StoiCalc* help, you can click on anything you like.

Suppose that your teacher wants you to discover the available options in *StoiCalc* help by just exploring around. Please examine the page and describe the options you see.

Please give me your initial reactions to this page. Feel free to explore this page as you normally would explore any other webpage. Please remember to think out loud about why you're clicking on things and

what your thoughts are. After you click on anything, do you find what you expected to see? Tell me about the page you are looking at. What options are available to you?

> ➢ If participant uses jump links: What happened when you clicked on [ITEM]? Is this what you expected to happen, why or why not?

[RESEARCHER STARTS FOLLOW UP INTERVIEW 1.1]

FOLLOW UP INTERVIEW 1.1:

1. Please give me your initial impressions about the usage of different tools in *StoiCalc*?
2. What do you think about the functions of the *StoiCalc*?
3. According to you, what should be the purpose of *StoiCalc*, what are its possible uses?
4. What are your usual strategies for solving " Molar Mass" problems?
5. What are your usual strategies for solving "Balancing Equations" problems?

Task 1.2.

>Your teacher is asking the following question [SHOW QUESTION – MOLAR MASS]. Please solve this question using available options in this page. As you move through this learning tool, I'd like you to act as you typically would when you use any other online learning tool, and please remember to think out loud about why you're clicking on things. After you click on anything, do you find what you expected to see?

- Tell me about the page you are looking at. What options are available to you?

  ➢If participant uses jump links: What happened when you clicked on [ITEM]? Is this what you expected to happen, why or why not?

FOLLOW UP INTERVIEW 1.2:

1. How easy or difficult was it for you to accomplish these tasks (problems) using *StoiCalc*?
2. Was there anything about the *StoiCalc* tools that made the tasks (problems) in Session 1 especially easy or difficult?
3. How easy or difficult was it for you to navigate around?
4. How do you think using *StoiCalc* has modified your usual way of approaching problem solving?
5. How do you think the *StoiCalc* improve your problem solving skills?

SESSION 2:

Task 2.1.

>Your teacher is asking the following question [SHOW QUESTION – BALANCING EQUATIONS]. Please solve this question using available options in this page. As you move through this learning tool, I'd like you to act as you typically would when you use any other online learning tool, and please remember to

think out loud about why you're clicking on things. After you click on anything, do you find what you expected to see?

- Tell me about the page you are looking at. What options are available to you?

  ➢If participant uses jump links: What happened when you clicked on [ITEM]? Is this what you expected to happen, why or why not?

Task 2.2.

>Your teacher is asking the following question [SHOW QUESTION – SOLUTIONS AND CHEMICAL REACTIONS]. Please solve this question using available options in this page. As you move through this learning tool, I'd like you to act as you typically would when you use any other online learning tool, and please remember to think out loud about why you're clicking on things. After you click on anything, do you find what you expected to see?

- Tell me about the page you are looking at. What options are available to you?

  ➢If participant uses jump links: What happened when you clicked on [ITEM]? Is this what you expected to happen, why or why not?

FOLLOW UP INTERVIEW 2.1:

1. How easy or difficult was it for you to accomplish these tasks (problems) using *StoiCalc*?
2. Was there anything about the *StoiCalc* tools that made the tasks (problems) in Session 2 especially easy or difficult?
3. How easy or difficult was it for you to navigate around?
4. How do you think using StoiCacl has modified your usual way of approaching problem solving?
5. How do you think the S StoiCacl improve your problem solving skills?

SESSION 3:

>Your teacher is asking the following question [SHOW QUESTION- DIMENSIONAL ANALYSIS]. Please solve this question using available options in this page. As you move through this learning tool, I'd like you to act as you typically would when you use any other online learning tool, and please remember to think out loud about why you're clicking on things. After you click on anything, do you find what you expected to see?

- Tell me about the page you are looking at. What options are available to you?
- If participant uses jump links: What happened when you clicked on [ITEM]? Is this what you expected to happen, why or why not?

FOLLOW UP INTERVIEW 3.1:

1. How easy or difficult was it for you to accomplish this task?
2. Was there anything about the *StoiCalc* tools that made this task especially easy or difficult?
3. How easy or difficult was it for you to navigate around?
4. What do you think about the OVER ALL advantages and disadvantages of using *StoiCalc*?
5. How do you think that using *StoiCalc* has changed the way of your thinking for problems solving?
6. How do you think that the *StoiCalc* help you to think?
7. How do you think about the *StoiCalc* influence on your learning?
8. How do you think about the *StoiCalc* influence on your attitudes to the learning chemistry?
9. What are your overall impressions of the *StoiCalc*?
10. What do you think the main purpose of *StoiCalc* is?
11. How do you compare *StoiCalc* to traditional pen – paper problem solving methods?
12. Do you have any other questions or comments?

APPENDIX D

Auditor's Report

Auditor Report

of

"Use Of Cognitive Artifacts In Chemistry Learning" by Ilker Yengin

The audit process includes an examination of the final document. The raw data, transcriptions, data analysis, results and conclusion – model diagrams checked. Moreover, audit trail contains all the raw data of Think Aloud Sessions that are object for the analyses.

The accuracy and legitimacy of the procedures and decisions to reach the Audit path was followed within these steps:

1. Data re-transcribed for random samples of 2 transcribes
2. Transcriptions checked for accuracy against original
3. Recording and amendments made
4. Data code checked using identified criteria
5. Decision-making processes mapped into diagrams identified and coding rechecked
6. Evidence for mapping (model) rechecked against to bias
7. The potential for bias or distortion has been examined in data collection and interpretation – analysis of data examined

As an independent researcher I transcribed a random of sample of audio records and verified them verbatim. Then I reviewed all the rest of the transcripts for accuracy against original. After the author worked on transcribed data file I checked the codes and themes to be sure there is no drift. Auditor examined the processes whereby data were collected and analyzed and interpretations were made and findings were validated.

Based on my readings and work with the author, I have suggested minor changes as following:

- Instead of having 5 themes merging one of them (Help me, save me) with the other (The StoiCalc Interface Leads the Mind)
- Moving some quotations under "Need For A Validation Method" to Help me save me sub-theme.
- Moving some quotations under Understanding StoiCalc's Expressions (Output) to User Habits and Transfer of Knowledge sub-theme.
- Replacing the name of "The power of Computers: StoiCalc Overcomes Limitation" with "The power of Computers: StoiCalc Overcomes Limitation of Calculating Slow"

The author made changes and I re-read the last document. As a result analysis and findings of this study are systematic, objective, and worthy. Procedures used in this study fall within "generally acceptable" practice. Based on that, I agree on that this is a trustworthy study.

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