Dirk Ifenthaler · Ria Hanewald *Editors*

Digital Knowledge Maps in Education

Technology-Enhanced Support for Teachers and Learners

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Preface

Digital Knowledge Maps in Education offers readers chapters that address, theory, research, and practical issues related to the use of digital knowledge maps in all aspects of education and draws predominantly on international perspectives.

Digital knowledge maps have generated much attention and interest among education practitioners and researchers over the last few years. Education institutions around the world are investing heavily into new technologies to provide online spaces within which to build resources and conduct activities. One of these spaces is digital knowledge maps with their power being "at a glance" visual representations that enable enriching, imaginative and transformative ways for teaching and learning, with the potential to enhance outcomes.

This edited volume seeks to provide a collection of knowledge mapping research and theoretical currents across a number of different perspectives with contributors who are both leading authorities and new voices from a wide geographical spread and from a variety of discipline backgrounds. It is intended as an introduction to those new in the field and interested in designing knowledge mapping projects but also an inspiration for seasoned knowledge mapping researchers as it presents recognised practices, exemplifies most recent methods and techniques as well as emerging trends and debates. While coherence is pursued, the editors deliberately choose to reflect the empirical, theoretical and methodological diversity commonly found in this rapidly growing field.

We organised the chapters included in this edited volume into four major parts: (I) digital knowledge maps in open, distance, and flexible learning contexts, (II) digital knowledge maps in collaborative learning contexts, (III) advances in assessment using digital knowledge maps, and (IV) case studies investigating digital knowledge maps.

In Part I, the six chapters address theoretical foundations and current issues using digital knowledge maps in education. Chapter 1 positions knowledge mapping in educational context but also in online environments. It provides an introduction to mapping for readers unfamiliar with the research field of mapping with a succinct yet comprehensive understanding of the relevant terminology, definition, techniques, software catalogue and research literature (Ria Hanewald and Dirk Ifenthaler, Chap. 1). Chapter 2 attempts to make sense of knowledge integration maps. It introduces Knowledge Integration Map (KIM) as a new form of digital knowledge map that aims to triangulate changes in learners' conceptual understanding through a multilevel analysis strategy that employs a combination of quantitative and qualitative methodologies (Beat Schwendimann, Chap. 2). A literature review on digital knowledge maps for comprehension and learning from hypertexts is provided in Chap. 3. The authors offer an overview of hypertext that help readers' navigation while distilling conditions under which concept maps are most effective and point out some educational implications (Franck Amadieu and Ladislao Salmerón, Chap. 3). Next, the use of digital knowledge maps for supporting tutors especially in their capacities to give effective explanations is emphasised. The authors present, describe and then test an approach that uses knowledge mapping to analyze instructional explanations in order to improve their effectiveness. The theoretical conception of the new method was then tested in a series of experiments to determine the validity of the measure (Andreas Lachner and Matthias Nückles, Chap. 4). The next chapter investigates pre-service teachers' thinking progression about e-Learning and its integration into teaching through concept mapping. It is based on a case study of nine undergraduate students in a pre-service teacher course engaged in e-Learning (Wan Ng, Chap. 5). The final chapter of this part shows how to raise teachers' awareness of the potential benefits of knowledge mapping and to introduce them to powerful, free software for their classrooms (Scott R. Garrigan, Chap. 6).

In Part II, the five chapters focus on the use of digital knowledge maps in collaborative learning contexts. In the first chapter of this part, the author seeks to improve ESL Learner's reading skills through collaborative work with digital knowledge maps (Pei-Lin Liu, Chap. 7). The next contribution reports research of digital knowledge mapping in individual and collaborative learning in primary school students specifically in science education (Andreanna K. Koufou, Marida I. Ergazaki, Vassilis I. Komis, and Vassiliki P. Zogza, Chap. 8). An essay towards a cultural–historical theory of knowledge mapping, specifically collaboration and activity in the zone of proximal development is presented (John Cripps Clark, Chap. 9). The use of digital knowledge maps within a Science Communication course taught at an Australian University with the view of increasing learning outcomes in future years is presented next. The chapter explores the impact and extent of the students' learning, especially their prior knowledge, their attitude about working collaboratively in small groups, their perspective on using technology-rich learning in general and using digital knowledge map in particular (Ria Hanewald and Dirk Ifenthaler, Chap. 10). The last chapter in this part describes the use of knowledge maps to foster peer collaboration in higher education. The authors combine Novakian concept maps and hierarchical reductionism methods to create a new pedagogical approach (Paulo Correia, Camila Cicuto, and Joana Aguiar, Chap. 11).

In Part III, the five chapters address advances in assessment using digital knowledge maps. The first chapter presents evidence that digital knowledge maps do indeed meet the criteria deemed necessary for effective formative assessment—they validly assess higher-order knowledge, identify specific conceptual strengths and weaknesses of students, provide feedback that can be used to effectively improve learning, and can be user friendly for both students and teachers (David L. Trumpower, Mehmet Filiz, and Gul Shahzad Sarwar, Chap. 12). Next, a method to capture and analyze differences in students' action sequences while creating a knowledge map is introduced (Allan Jeong, Chap. 13). Automatically generated knowledge maps that aggregate expertise from several domains to foster a common understanding is proposed in the next chapter. The function and use of the knowledge map was illustrated with the example of team meetings in companies and the potential miscommunication that may result in loss of productivity and outcomes, which application of the mapping approach can help to overcome or at least reduce (Pablo Pirnay-Dummer, Chap. 14). Next, the problem of using digital knowledge maps for formative assessment not only in university settings but also for primary and secondary school students is addressed (Heiko Krabbe, Chap. 15). The final chapter of this part sees digital knowledge maps as the foundation for learning analytics through instructional games. It reports on an assessment instrument and uses an illustrative case of gameplay behavior to show how digital knowledge maps can teach and assess game-based environments (Debbie Denise Reese, Chap. 16).

In Part IV, three case studies investigating the instructional practicability of digital knowledge maps are presented. The first chapter of this part positions digital knowledge mapping as an instructional strategy to enhance knowledge convergence and thus examine knowledge maps as an instructional tool (Darryl C. Draper and Robert F. Amason, Jr., Chap. 17). The next case study uses knowledge maps as a teaching tool for financial literacy with the task for students being the construction of individual maps that reflect their assets and debts in order to capture and develop their financial competency and track private consumption and money management (Daniela Barry, Nina Bender, Klaus Breuer, and Dirk Ifenthaler, Chap. 18). The final case study explores the views of four academics from different disciplines in using digital knowledge mapping for the first time with their students (Gregory MacKinnon, Rohan Bailey, Patricia Livingston, Vernon Provencal, and Jon Saklofske, Chap. 19).

Clearly, the field of digital knowledge mapping is a dynamic one, particularly in the context of new and emerging technologies and this book gives a sense of the creative possibilities in using digital knowledge maps and highlights current trends and future directions for educators and instructional designers.

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About the Authors

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Paulo Correia (prmc@usp.br) is Assistant Professor at the University of São Paulo. He is PhD in Analytical Chemistry (2004), and since 2005 he changed his research interests to science education and instructional design. The use of concept mapping for teaching and learning purposes has driven the activities of the Cmapping Research Group at the School of Arts, Sciences and Humanities. The research projects under development aim (1) to develop instructional materials to training beginners to become proficient map makers, and (2) to foster collaboration work in multidisciplinary teams using concept maps to improve communication.

John Cripps Clark (john.crippsclark@deakin.edu.au) is a Lecturer in Science Education at Deakin University, Australia and teaches and researches in Science and Technology Education and Science Communication. He has also taught in universities, secondary and primary schools in Victoria and New South Wales (NSW). He has conducted research in primary science education in rural and urban schools in Victoria, NSW and the Australian Capital Territory focussing on exemplary primary teachers of science and their use of practical activities. His current research projects include: multi-modal online concept mapping, video-stimulated pedagogical reflection, pre-service teachers' professional experience, cultural historical activity theory, and evidence-based practice in education. John founded and runs a long running international discussion group in cultural historical activity theory. He conducts teacher professional development in Australia, Vanuatu and Lithuania.

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Scott R. Garrigan (scott.garrigan@lehigh.edu) teaches masters and doctoral courses in instructional design and technology as a Professor of Practice in Lehigh University's College of Education. His varied career in public education includes school district positions from classroom teacher to district technology director. During that time he designed and implemented a 10,000-node district network and a one-to-one laptop program for four middle schools. As a software developer in 1990, he designed and implemented a pupil reporting system for eight elementary schools using state-of-the-art automated scanning and natural language technologies. Dr. Garrigan served as a statewide director of professional development for the Center for Advancement of Partnerships in Education; during that time he conducted professional development for 8,000 K-12 and higher education faculty. He is a frequent session and workshop presenter at regional and national conferences in educational technology (PETE&C, ISTE/NECC). His interest in knowledge mapping is an intersection of interests in cognition, knowledge organization, education, and technology.

Ria Hanewald (r.hanewald@yahoo.com) is a teacher mentor for CfBT Education Trust, currently on assignment in Malaysia. There, she provides professional learning and curriculum support for English teachers. Prior to that, she has spent a decade lecturing, researching and managing large, complex projects funded by Australian Research Council (ARC) grants at several universities in Australia. During that time, Dr. Hanewald contributed to securing more than half a million dollars (AUD $ 588,000) in research and consultancy monies and (co-)authored 10 books, 13 book chapters, 22 journal articles and 47 conference papers. In addition, she presented key notes, workshops, seminars and lectures to audiences in Australia, Canada, Germany, Japan, Spain, New Zealand, Thailand, Turkey, the UAE and the USA. Her contributions to the wider community include the role of editor of the ICT in Education Journal and consulting editor for the Australian Journal of Teacher Education (AJTE), serving on the state council of the Computer in Education Group of Victoria (ICTEV) and as a reviewer for several journals (MERLOT, Higher Education Studies, MOJEM and AJEP). Dr. Hanewald's research interests traverse e-learning environments, curriculum development, academic standards, teaching improvement, quality assurance and enhancement as well as student engagement and learning.

Dirk Ifenthaler (dirk@ifenthaler.info) is currently Manager of Applied Research and Learning Analytics at Open Universities Australia. His background is in cognitive psychology, educational technology, statistics and teacher education. He developed automated and computer-based methodologies for the assessment and analysis of graphical and natural language representations (SMD, HIMATT, AKOVIA). Additionally, he developed components of course management software and educational simulation games (DIVOSA, SEsim). He is also interested in the development of educational software, game-based assessment and learning management systems as well as technology integration into the classroom with a specific focus on mobile technologies. Dr. Ifenthaler's research outcomes span numerous (co-)authored books, book chapters, journal articles and international conference papers. He was a 2012 Fulbright Scholar-In-Residence at the Jeannine Rainbolt College of Education, The University of Oklahoma, USA.

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Contents

Part I
Digital Knowledge Maps in Open, Distance, and Flexible Learning Contexts

Chapter 1
Digital Knowledge Mapping in Educational Contexts

Ria Hanewald and Dirk Ifenthaler

Abstract This chapter provides an introduction to knowledge mapping for the novice reader. It will start with a brief overview of the historical origins of concept maps and the learning theories that underpin them. It is followed with a discussion on the various definitions of maps by the authors who are postulating their own definition. Additional terminology is presented in the section explaining the anatomy of a knowledge map, while a simple ten-step process guides readers through the creation of their own map. This can either be a concept or a mind map, with the difference explained in the next section. Maps can be constructed either manually or digitally, with a short explanation of the advantages and disadvantages of each approach before launching into a section that provides an indication of various mapping software and their main features. The chapter concludes with a synopsis of the current knowledge base in the research literature on knowledge maps in educational contexts. It will enable familiarisation with the field and provide a foundation for the following chapters containing empirical and theoretical work, which form the remainder of the book.

Keywords Historical origins • Map types • Definition • Characteristics • Software

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1 History of Concept Maps

Concept mapping is a technique first developed in the 1970s by Joseph D. Novak (1991) to represent understanding of a subject matter in multimodal forms. His work is underpinned by David Ausubel's (1968) learning theory which proposed that the most significant factor in learning is the learner's already existing knowledge as it forms the foundation for new knowledge. Meaningful learning occurs when the learner is able to make connections between what is already understood and what is still to be comprehended. This notion of meaning learning was in stark contrast to the prevailing learning method of the time, which was that of rote learning. Instead of merely memorising facts and reiterating the teacher's explanations, Ausubel Assimilation theory signalled the power of understanding the material and thus the significance of meaningful learning. He suggested that knowing rather than remembering was the key. It could be achieved by organising the knowledge and then building on these already familiar concepts through direct experiences or observation of objects which then constructed new knowledge. Novak (1991) hypothesised that this process of 'knowledge elaboration' was supported if learners drew graphic organisers to visualise and organise what they already know and then actively build their knowledge by adding the new information. In effect, these graphic organisers or concept maps were the bridge that connected old and new understanding, and his subsequent work on visualisation of knowledge and knowledge evolution in children's science learning guided the establishment of the field of concept mapping. Initially, maps were manually created, but the arrival of personal computers and later on the invention of the Internet offered electronic concept mapping (Buzan & Buzan, 2000; Cañas et al., 2004). At the time, Novak worked at Cornell University and was instrumental in developing the Web-based C-map tool by the Human Institute for Machine Recognition. It made digital concept mapping available for the public in open-source mode. Since then, a range of self-contained software packages and Web-based applications have been developed and are either offered as open-source or as proprietary products. A range of powerful and even mobile devices in addition to the advent of diverse Web 2.0 applications allow individual and collaborative map construction in synchronous and asynchronous mode. These recent advancements afford digital map construction on a large scale and across a range of disciplines not only for teaching and learning purposes but also as a communication tool, an assessment tool and as a means for conducting research. Given the developments of the last two decades in terms of emerging technologies, there is a limited yet growing body of knowledge on the use of digital knowledge maps in educational settings with most publications stemming from developed countries which have the electronic infrastructure to support such undertakings.

2 Various Types of Maps, Characteristics and Definitions

All maps are at their most basic graphical representations of ideas or concepts. Their power is in the visualisation, simplistically coined in the adage that ‘a picture is worth more than a thousand words’. At a glance, complex ideas can be seen what might otherwise only be described in a long narrative. While the conveyed information might be the same, the medium of maps allows a shifting from text to image. There are a number of terms in use to describe maps, often used interchangeably which can lead to confusion. However, each type of map has its own suitability for a particular purpose or content. This section is intended to clarify and exemplify the various types of maps and gives a brief description of their characteristics to distinguish them from each other.

The two most widely used kinds of maps are mind maps and concept maps. Mind maps are also known as spidergrams or spidergraphs—especially in the United Kingdom—due to their appearance. Typically, they start with a central point, which is the key idea or word. Other ideas or words are radiating like spokes from the hub in an almost intuitive fashion through a free flow of thoughts, which encourages brainstorming (Nückles, Gurlitt, Pabst, & Renkl, 2004).

Mind maps use a central word, idea, or other item and arrange others intuitively around the central word (see Fig. 1.1). A mind map starts with a key notion that radiates out into branches. These tree structures set up a non-linear graphical arrangement, which promotes brainstorming. This free flow of ideas generates and charts elements without the immediacy of having to establish an intrinsic conceptual framework (Ng & Hanewald, 2010, p. 82). This unstructured generating of impressions inspires the quick capture of thinking on a particular notion. The resulting mind map can stand on its own or be used as a starting point for a concept map. In contrast, concept maps are structured, indicating relationships between the concepts or the ideas.

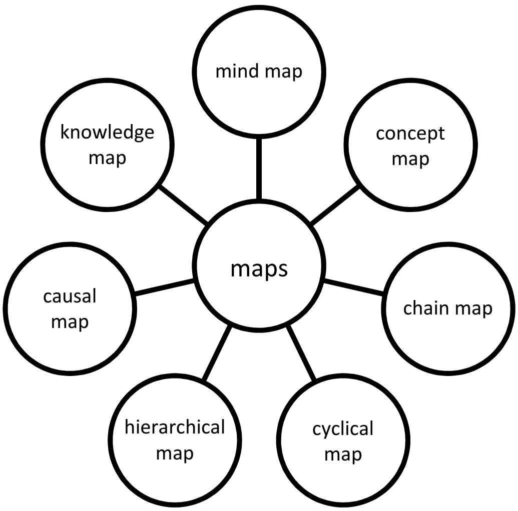

Fig. 1.1 Example of a mind map

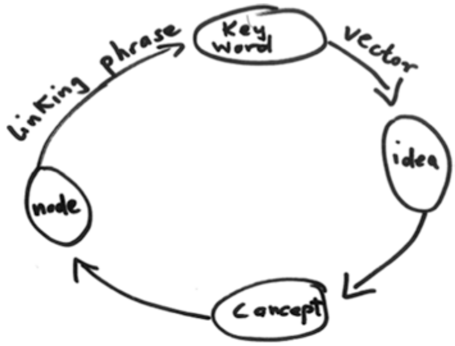

Fig. 1.2 Example of a cyclical map

Concept maps are graphical tools for organising and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts (Novak & Cañas, 2006, p. 1). Within concept maps there are variations such as chain (also known as sequential) maps, cyclical maps and hierarchical maps. Chain or the so-called sequential maps are used to indicate a sequence of events, for example in time lines or in a step-by-step process to show a succession of steps.

Cyclical maps are normally used to show how various aspects are connected and linked together in a closed loop (see Fig. 1.2). They are mostly found in the natural sciences as they ideally suit the display of biological systems such as the nutrient cycle or ecosystem (i.e. water cycle, air cycle, photosynthesis).

Hierarchical maps are also called tree structures, as concepts shoot off like branches from a tree (see Fig. 1.3). These maps are read from the top to the bottom as the most general concept is at the top of the hierarchy or the tree. At the lower part of the hierarchy are more specific concepts, which can also be cross-linked. Both versions, the pure hierarchical maps and the maps using cross-links, are regarded "… as the most appropriate tool for representing static knowledge" (Ng & Hanewald, 2010, p. 83). Typical examples of typical hierarchical maps are family trees or food chains that show the feeding relationships of species within an ecosystem.

Initially, hierarchical maps were heavily promoted by Novak (1998) and became therefore also known as 'Novakian' maps. However, others (Ruiz-Primo & Shavelson, 1996) were less enthusiastic arguing that the map's hierarchical structure forces the information to be manipulated in such a way that it fits the tree configuration. Instead, they proposed that the organic growth of the knowledge should shape the map's structure.

Another type of concept map is a causal map, which—as the name indicates—provides a way of representing causal relationships, that is, the links between the nodes represent causality. It is suited to usage with predictions and experimental intervention as it infers causal structures from patterns of evidence and is often used as an aid to strategic thinking and planning (Bryson, Ackermann, Eden, & Finn,

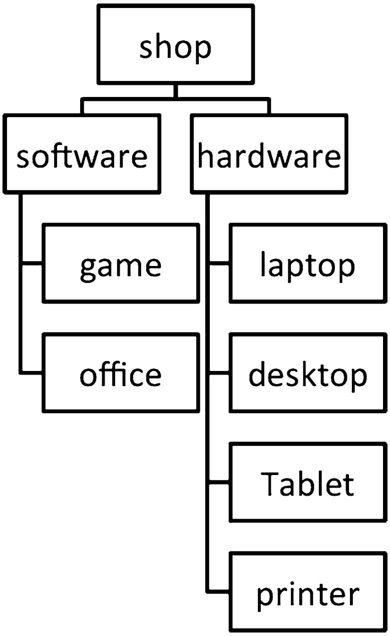

Fig. 1.3 Example of a hierarchical map

2004). Markíczy and Goldberg (1995, p. 305) see casual mapping as a "… tool for exploring individuals' idiosyncratic beliefs". They define causal maps as "… representations of individuals (or groups) beliefs about causal relations"; they have two properties with the first being relevance and the second being the influence on the relationship, which can be weak, moderate or strong (p. 306).

In summary, each map has its own characteristics and inert strength. Hence users will need to decide for themselves which type of map is most suitable for their purpose. For the purpose of this book, the following definition of knowledge maps has been crafted:

> *A knowledge map is a graphical display of information in which the importance and relationships between the various elements of knowledge are portrayed in the form of a map.*

3 Anatomy and Terminology of a Map

This section dissects a map into its various parts and labels them with the appropriate terminology to give the reader relevant vocabulary used in the remainder of the book.

At the core of any map is a concept, word or idea in the so-called node, which is usually a circle, oval or rectangle. The nodes are linked with lines called vectors, which can be non-directional, unidirectional or even bidirectional. The direction is indicated through arrows at the end of the line; hence no arrows delineates no direction. The vectors show the relationships between the nodes and can be either unlabelled or labelled. Labelled vectors further clarify the connections between the concepts displayed in the nodes. The words or the descriptions used on the vectors are called ‘linking phrases’ (Ifenthaler, 2010b).

4 Guidelines for Creating Knowledge Maps

Figure 1.4 shows the seven-step creation of a digital map starting with a key concept, word or idea that is placed in the so-called node, which is usually a shaped box. A number of related other concepts, words or ideas are brainstormed (Step 2) and placed in additional nodes. These are then connected with lines which are known as vectors. The vectors are either left as they are without direction or given one arrow to indicate a one-way direction or given two arrows to show relationships that go into both directions (Step 3). The vectors are labelled with words or the so-called linking phrases to further clarify the relationships of the concepts (Step 4). The concepts are now ordered from their random position during the brainstorming to an organised position according to their relevance and relationship with the key concept (Step 5). Various colours, different sized fonts, sizes or italics and bold can now be used to highlight connections between various ideas or concepts (Step 6). The final step (Step 7) comprises the addition of images, sound files or hyperlinks to add information to the nodes. The map could now be considered complete unless the creator wishes to continue the process by repeating the process from Step 2 to Step 7 to elaborate on the map or by inviting other people to collaborate on the extension of that map.

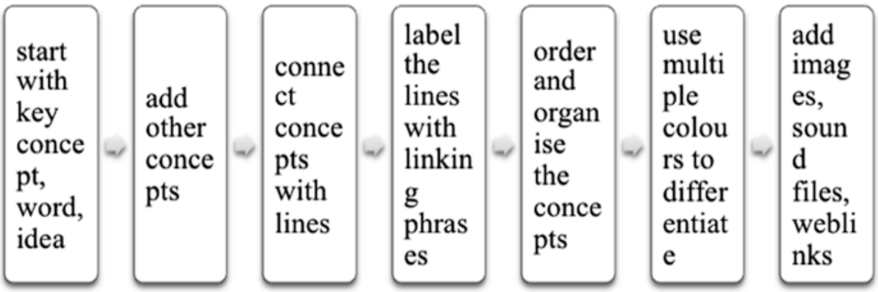

Fig. 1.4 Example of a chain map illustrating the seven-step process of creating a digital map

5 Approaches to Mapping

Apart from the various shapes of maps, their associated characteristics and functionalities, Dansereau (2005) differentiated three approaches to mapping: information maps, guided maps and free-style maps. Information maps are generated by experts to present information but also to orient and navigate through a subject matter. These maps can be used for teaching and learning as models of a particular concept or topic but also as assessment tool. In that case, information maps generated by experts are used as a 'gold standard' against which learner-generated maps are measured and marked against. Guided maps are generated by learners but with the provision of adequate scaffolding such as a number of predefined nodes or concepts and perhaps even some linking phrases that the teachers have created and made available for use. Rather than starting with a blank slate, these elements act as building blocks and are especially helpful for novices unfamiliar with the mapping technique or the subject matter as the scaffold reduces cognitive load. Free-style maps are generated by the learner without any constraint or support.

6 Individual Mapping Versus Collaborative Mapping

Another approach of working with maps is the collaborative mode either in pairs or in groups compared to individually constructed maps. Kwon and Cifuentes (2007) stated that building and sharing a map with others require communication and negotiation, which in turn guide learners to growth in their conceptual understanding. The collaborative process and the high level of social interaction increased each person's knowledge which would not have been possible if they would have worked on their own.

The notion that working in a team to develop a map is more beneficial than working by oneself is supported by Coutinho (2009) in her study of 29 teachers who were completing a Master of Education degree. She found that the interaction in teams helped the group in developing their understanding of the content under study further. In comparing the same concept maps on a specific topic designed by groups with those designed by individuals, she found statistic differences. The scores for each concept map are measured with collaboratively constructed maps being statistically significantly better, with greater understanding of the content and higher processing of related ideas as students pulled their knowledge together. In addition to the combined group effort being superior to that of an individual person's attempt, students became responsible for their own learning as well as that of others as they were working together for a common purpose.

Hwang, Shi and Chu (2011) are another group of researchers whose work supports the belief that collaborative concept mapping achieves higher learning outcomes. They had 70 participants whom they separated into three distinct groups. One group was learning the subject matter without any concept mapping, another group used pen and paper to draw concept mapping while learning the subject matter and a third group worked collaboratively using digital concept mapping to learn the same material. In the pretest scores, there was no difference in the student understanding. However, in the post-test results, the students who used collaborative digital concept mapping showed significantly better learning achievements than the students who learned the same materials with other methods. The participants in the study also displayed improved attitudes towards science learning, enhanced confidence in their peers and higher expectations of learning collaboratively. In addition, collaborative work encouraged students' engagement and self-efficacy in learning as well as their motivation to communicate and collaborate with their peers.

7 Comparison of Manual Versus Digital Maps

Traditionally, maps were drawn by hand (see Fig. 1.2), but the advent of computers has made the creation of electronic maps possible. Digitally designed maps can be created by either using online options that can be downloaded from the Internet or self-contained software that can be installed on desktops or laptops. Ng and Hanewald (2010) compared manually created concept maps to digital version and noted the electronic versions' advantage of the non-linear electronic structures that are afforded through hypertext. This flexibility enables not only infinite changes but also the insertion of media such as still images, videos, sound files and connections to hyperlinks to further illustrate clarifications. Some of the mapping software has additional functions such as an auditory facility that permits short voice recordings to explain nodes or relationships. Users are thus able to easily create and revise a map as they increase their knowledge and understanding of the subject matter.

The advantages of hypertext are further elaborated by Amadieu, van Gog, Paas, Tricot and Mariné (2009) as dynamic exploration of content that allows users to control their own process of knowledge construction. However, they caution that a drawback is the potential cognitive overload and disorientation. This can occur if learners grapple with the challenge of establishing mental connection while at the same time negotiating pathways across the hypertext environment which requires simultaneously coping with the conceptual and the physical space.

The most obvious advantages of manual maps are the low cost and low technology involved and their spontaneous production. Hand-drawn maps can be designed on almost anything (i.e. a napkin, paper table cloth, white board) as only a surface and writing implement are necessary. Hence, hand-drawn maps can be produced anywhere, whereas digital maps will always need a device (i.e. laptop, desktop) which is not only costly to purchase but may have to be also powered up before it is ready to use. The disadvantage of hand-drawn maps is the permanent fixed manner with little option to modify the map other than to engage in the messy and time-consuming task of erasing or rewriting a manually composed map.

The use of mapping software that is freely and easily available on the Internet, with a range of sophisticated features that are quick to master due to their almost intuitive use, enables the creation of large and complex digital maps. They can be instantly and infinitely revised, remixed, reproduced, redistributed and displayed in various formats (e.g. jpg, .png, .svg, doc, docx, ppt, interactive whiteboards, wikis, blogs or web pages). Electronic versions can be produced—either synchronous or asynchronous—by one person or a group of people and then revised, stored, printed out, replicated, exported into other files or deleted.

8 Examples of Mapping Software

Digital maps can be created with a variety of software packages that are available commercially. For example, the Microsoft Office Suite contains Word Smart Art Office which offers a number of graphics templates. Other proprietary products specifically created for mapping can be installed on a desktop or a laptop and even networked within a confined work environment. Their costs are justified by additional features such as 3D views with an option to rotate angles and 'fly' through the map.

The advantage of electronically based or also called online mapping tools is the collaborative element as it allows other users and oneself access to the constructed maps from anywhere and anytime. This affords working in pairs or teams on maps. There are now mapping software available for mobile applications. The examples of digital mapping software below are by no means an exhaustive list and are not an endorsement of particular applications. They are listed in alphabetical order and were merely chosen to give readers a starting point to explore the various options and decide on their preference.

Free available mapping tools:

- *Bubb.us* (https://bubbl.us/)
  This mind mapping software is primarily text based but without the option to format except for the colour icon which indicates hierarchies. It is easy to use as text 'bubbles' are created and connected with a paper clip. The mouse can be used to zoom in and out of the map, and there is also a drag-and-drop action to move around the work area.
- *Cmap tool* (http://cmap.ihmc.us)
  This is an open-source Web-based concept mapping tool that was developed by the Institute for Human and Machine Cognition (IHMC), a not-for-profit research institute of the Florida University System. It can be downloaded onto a personal computer where users can create their maps, access them from anywhere and share them with others to work together. This can be done by browsing and editing the maps while simultaneously chatting and critiquing it for example in a discussion forum or via post-it-notes which can be placed on the map with comments.
- *Free Mind* (freemind.sourceforge.net)
  This is a no-cost mind mapping software with smart drag 'n drop facility to copy nodes or styles of nodes, multiple selected node and dropping of texts or list of files from outside. However, it is limited to one user at a time as the locking mechanism prevents others from working on the same map simultaneously.

- *Thinkature* (http://thinkature.com/)
  This is a Web-based virtual workspace that allows for collaboration with others through synchronous chat about their maps while users can draw free-form shapes, include images and add and edit text.

  Commercially available mapping tools:

- *Creately* (http://creately.com/)
  A software program that enables online diagramming and collaboration on flow charts, wire frames and mind maps for up to 20 people. It is a cross platform and runs on Windows, Mac and Linux. There are ready-made templates and an extensive library of object sets.
- *Inspiration Software, Inc.* (http://www.inspiration.com/)
  Inspiration 8 runs on Mac OSX and Microsoft Windows, offering a variety of techniques from Webs, idea maps and plots to concept maps which encourage thinking.
- *Conceptshare* (http://www.conceptshare.com/)
  This collaborative environment enables sharing, reviewing and commenting by participants in real-time chat with annotation tool such as pencil, line and text to allow for the mark up of created design.
- *Kidspiration* (http://www.inspiration.com/productinfo/kidspiration/index.cfm)
  This package is also published by Inspiration Software Inc but aimed at a much younger audience, specifically at primary school students aged 5–10 years old. It offers simpler yet colourful ways to present and connect ideas and assists in early literacy development.
- *Gliffy* (http://www.gliffy.com/)
  An online diagramming software which enables the design of flow charts, diagrams and floor plans but also allows access to a library with shapes and interfaces. In addition, users can import their own images such as company logos or particular background to customise their design and then protect it by opting for the read-only version.
- *Topicscape* (www.topicscape.com/)
  Computer software that allows users to organise work, reference information, day-to-day documents, images, emails and web pages in a choice of either a two-dimensional or a three-dimensional format. The drag-and-drop feature allows for easy moving of files and information, while the 'flying' feature affords easy navigation through the 3D scene.

9 The Current Knowledge Base

This section presents a snapshot of what is known and what is not known about knowledge mapping in the research literature, gaps in the research and areas for future research. However, due to the sheer volume of literature on concept mapping in educational contexts, a summative style of the major elements only will be adopted.

There are currently 'three major field where concept mapping is used, namely as a teach-and-learn strategy tool, a cooperation process application, as a tool for knowledge gathering, diagnosis, and modelling' (Mandl & Fisher, 2000).

Knowledge maps can be used as a tool for support of learning in several ways: as a note-taking strategy for learners to record what they understand from a lecture or a classroom presentation and as some kind of schematic summary to show what learners know about a topic after reading a book or a chapter or as a planning tool for assignments or essays to set out the flow of their piece. In essence, their function in the former case is to organise and present information whereas in the latter instance it serves as an 'advance organiser', that is a global overview of the material.

While these approaches often involve a single learner, collaborative learning in pairs, small or large groups to discuss and question and debate understandings of particular topics are a widely used strategy with significant research effort in that area as reviewed under Sect. 6.

A number of studies have investigated the effectiveness of knowledge mapping as a learning tool (Al-Diban & Ifenthaler, 2011; Chang, Sung, & Chen, 2001; Esiobu & Soyibo, 1995; Gurlitt & Renkl, 2010; Hilbert & Renkl, 2008; Ifenthaler, 2010a; Ifenthaler, Masduki, & Seel, 2011; Johnson, Ifenthaler, Pirnay-Dummer, & Spector, 2009; Jonassen & Cho, 2008; Nicoll, Francisco, & Nakhleh, 2001; Schmid & Telaro, 1990).

Assessment of learning using knowledge maps is another area that has received research interest, either for formative or summative assessment procedures. While the former can be at any point in the learning process, the latter is usually at the end of it and most likely carrying a grade. Some researchers have devised various scoring methods for the components and structure of knowledge maps (Al-Diban & Ifenthaler, 2011; Ifenthaler, 2010a, 2010b; Novak & Gowin, 1984). In allocating points to components and structures of concept maps the approach ultimately compares students against each other and assesses a student's performance in relation to their peers.

Another approach was taken by Ruiz-Primo and Shavelson (1996) who compared students' maps to those of an expert. Expert maps can be created by either one or more teacher(s), a specialist or some person of authority on the subject matter. The comparison procedure can utilise computerised techniques to ease the time-consuming task of manually calculating the scores of the maps' structure.

Recently, computer-based methodologies have been developed for an automated assessment and analysis of knowledge maps (Ifenthaler, 2010b; Ifenthaler & Pirnay-Dummer, 2013; Pirnay-Dummer, Ifenthaler, & Seel, 2012; Pirnay-Dummer, Ifenthaler, & Spector, 2010). Advanced databases and network technologies contribute an especially wide variety of applications for an efficient assessment of individual and group data (Ifenthaler & Pirnay-Dummer, 2013). Leading methodologies for an automated assessment and analysis of knowledge maps are Pathfinder (Schvaneveldt, 1990), ALA-Reader (Clariana, 2010), jMAP (Shute, Jeong, Spector, Seel, & Johnson, 2009), HIMATT (Pirnay-Dummer et al., 2010) and AKOVIA (Ifenthaler & Pirnay-Dummer, 2013).

10 Conclusion

This chapter covered the main issues in relation to knowledge maps. It was intended to equip readers unfamiliar with the research field of mapping with a succinct yet comprehensive understanding of the relevant terminology, definition, techniques, software catalogue and research literature. The overview is aimed at educators although it is also applicable to researchers and students in education contexts.

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Chapter 2
Making Sense of Knowledge Integration Maps

Beat A. Schwendimann

Abstract Digital knowledge maps are rich sources of information to track students' learning. However, making sense of concept maps has been found challenging. Using multiple quantitative and qualitative methods in combination allows triangulating of changes in students' understanding. This chapter introduces a novel form of concept map, called knowledge integration map (KIM), and uses KIMs as examples for an overview of concept map analysis methods. KIMs are a form of digital knowledge maps. KIMs have been implemented in high school science classrooms to facilitate and assess complex science topics, such as evolution. KIM analysis aims to triangulate changes in learners' conceptual understanding through a multilevel analysis strategy, combining quantitative and qualitative methodologies. Quantitative analysis included overall, selected, and weighted propositional analysis using a knowledge integration rubric and network analysis describing changes in network density and prominence of selected concepts. Research suggests that scoring only selected propositions can be more sensitive to measuring conceptual change because it focuses on key concepts of the map. Qualitative analysis of KIMs included topographical analysis methods to describe the overall geometric structure of the map and qualitative analysis of link types. This chapter suggests that a combination of quantitative and qualitative analysis methods can capture different aspects of KIMs and can provide a rich description of changes in students' understanding of complex topics.

Keywords Concept mapping • Evaluation • Knowledge integration maps • Science education • Network analysis

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1 Introduction

Concept maps are rich sources of information about students' understanding and can be used as complementary assessment items in the pretest and posttest (Rice, Ryan, & Samson, 1998). Concept maps can serve as sources for several different forms of information: presence or absence of connections, quality of connections, different types of link labels, different types of networks, and spatial placement of concepts. Many existing analysis methods do not capture the manifold alternative concepts students represent in a concept map and tend to lose information by representing concept map scores as a single number, for example by scoring components of the concept map qualitatively by counting the number of concepts, links, hierarchy levels, and examples (Novak & Gowin, 1984); by qualitatively evaluating propositions (McClure, Sonak, & Suen, 1999); or by comparing the students' concept map with a benchmark map (for an overview of concept mapping analysis methods see Cathcart, Stieff, Marbach-Ad, Smith, & Frauwirth, 2010). However, no single scoring method can accurately describe all different forms of information in concept maps. This chapter introduces a novel form of concept map, called knowledge integration map (KIM), to illustrate the need for a more comprehensive multi-level analysis method for concept maps. KIM analysis combines propositional, network, and topological analysis methods. Using quantitative and qualitative analysis methods in combination can provide complementary insights of connections between concepts and allows tracking changes in the quality of concept maps.

1.1 Concept Maps and Knowledge Integration

Concept map activities can support eliciting existing concepts and connections through the process of visualizing them as node-link diagrams. The explicitness and compactness of concept maps can help keeping a big picture overview (Kommers & Lanzing, 1997). The "gestalt effect" of concept maps allows viewing many concepts at once, increasing the probability of identifying gaps and making new connections. Generating concept maps requires learners to represent concepts in a new form which can pose desirable difficulties (Bjork & Linn, 2006; Linn, Chang, Chiu, Zhang, & McElhaney, 2010)—a condition that introduces difficulties for the learner which slow down the rate of the learning and can enhance long-term learning outcomes, retention, and transfer. The process of translating concepts from texts and images to a node-link format may foster deeper reflection about concepts and their connections (Weinstein & Mayer, 1983) and prevent rote memorization (Scaife & Rogers, 1996). Throughout a curriculum, learners can add new concepts to their existing concept map. Unlike textbooks, concept maps have no fixed order and may thereby encourage knowledge integration strategies. For example, a student may decide to add the most important or most central concept first. Developing criteria to select concepts requires deeper processing than the student might normally exercise when reading text.

Table 2.1 Concept mapping for knowledge integration

Knowledge integration process	KIM activity
Eliciting existing ideas	KIMs can be used as a pretest activity to elicit existing concepts
Adding new ideas and connecting to existing ideas in repertoire	New concepts can be added to existing propositions in the KIM. If several alternative relations between two concepts are possible, students have to decide which one to use in the map. If applicable, students decide which concepts to add to the map
Distinguishing/critiquing ideas	After adding new concepts, concepts can be rearranged into new groups, and the KIM network structure might need revision to reflect the new concepts
Sorting out ideas/refining	Different sources of evidence can be used as reference to sort out concepts and further refine the KIM
Applying ideas	KIMs can be used as resources to generate explanations of scientific phenomena

Students need to develop meta-cognitive strategies to distinguish alternative concepts, for example through predicting outcomes and explanation generation (Bransford, Brown, & Crocking, 2000a). The scaffolded process of adding and revising concept maps requires students to decide which concepts and connections to include. The decision-making process may foster the generation of criteria to distinguish pivotal concepts. Clustering-related concepts in spatial proximity can support learners' reflections on shared properties of and relations between concepts. Cross-links between related concepts can be seen as indication for knowledge integration across different contexts. Concept maps may support making sense of concepts by eliciting semantic relationships between concepts (see Table 2.1 above).

Knowledge integration suggests that a successful curriculum starts by eliciting concepts about scientific phenomena. Learners need tools to elicit their concepts and distinguish alternative concepts. Concepts (or ideas) cannot be understood in isolation. Concepts need to be connected to existing concepts, and their meaning can only be understood within such an integrated framework (Bruner, 1960). Learning a concept means seeing it in relation to other concepts, distinguishing it from other concepts, and being able to apply it in specific contexts. To learn a subject is to have actively integrated key concepts and the relations between them.

Knowledge integration activities are designed to help learners construct more coherent understanding by developing criteria for the concepts that they encounter. Research suggests that concept mapping is especially efficient, in comparison to other interventions such as outlining or defining concepts, for the learning of relations among concepts (Canas, 2003). Concept maps as a knowledge integration tool allow eliciting and critiquing concepts and relations between concepts. The visual format of concept maps can foster critical distinctions between alternative concepts and relations, either individually or through collaboration in communities of learners.

Cognitive science (Bransford et al., 2000a) research found that new concepts need to be connected to existing concepts to be stored in long-term memory. Eliciting existing concepts brings them from long-term memory to working memory. Learners make sense of new concepts by integrating them into their existing repertoire of concepts.

Knowledge integration suggests that concepts should be presented in multiple contexts and support generation of connecting concepts across contexts. Multiple representations of concepts (for example dynamic visualizations, animations, pictures, diagrams) can facilitate learning and performance supporting different accounts of scientific phenomena (Ainsworth, 2006; Pallant & Tinker, 2004), for example by complementing each other or constraining interpretations (Ainsworth, 1999). However, having learners make connections between different representations can be challenging as they are connected through multiple relations that are often not intuitively obvious to the learner (Duncan & Reiser, 2005).

2 Knowledge Integration Map

Knowledge needs to be structured to be meaningful (Bransford, Brown, & Crocking, 2000b). David Ausubel (Ausubel, 1963; Ausubel, Novak, & Hanesian, 1978) discussed the importance of the hierarchical arrangement of information within organizational tools. Evolution concepts, however, are not necessarily hierarchically organized but consist of concepts from different fields. Research indicates that re-representing text in a concept mapping format can be done in a fairly automated way without requiring construction of new or revision of existing connections between concepts (Holley, Dansereau, & Harold, 1984; Karpicke & Blunt, 2011). Greater benefit may arise if the concept map activity constrains concepts and relations to a novel format, for example by providing biology-specific scaffolding to distinguish "genotype concepts" and "phenotype concepts." The distinction between phenotype and genotype is fundamental to the understanding of heredity and development of organisms (Mayr, 1988). Bruner stated that "virtually all cognitive activity involves and is dependent on the process of categorizing" (Bruner, Goodnow, & Austin, 1986), p. 246). Providing such scaffolding for sorting out and grouping related concepts into categories can support knowledge integration of evolution concepts.

A novel form of concept map, called KIM, aims to elicit and scaffold cross-field connections through the spatial arrangement of concepts in specified levels (see Table 2.2). Markham (Markham, Mintzes, & Jones, 1993) found that the major differences in content knowledge of novices and experts are a lack of integration, lack of cross-links between concepts, and a limited number of hierarchical levels. Integrating complex concepts in fields such as evolution requires connecting concepts from different fields (for example genetics, cell biology, and evolution).

Concept mapping tasks are found in many different forms and provide different amounts of constraints. The task ranges from low directed maps where students can

Table 2.2 Characteristics of knowledge integration maps (KIMs)

Biology-specific levels	This characteristic combines aspects of concept mapping with aspects of Venn diagrams. The KIM drawing area is divided into several domain-specific vertical levels, for example genotype and phenotype. This arrangement requires learners to (a) generate criteria and categorize concepts, (b) sort out concepts into according levels (clustering), and (c) generate connections between concepts within and across levels. Sorting out and grouping concepts spatially according to semantic similarity require learners to generate criteria and make decisions about information structure that is latent in texts (Nesbit & Adesope, 2006). This is expected to support knowledge integration by showing concepts in contexts to other concepts and eliciting existing (and missing) connections within and across levels. Cross-links are especially desirable as they can be interpreted as "creative leaps on the part of the knowledge producer" (Novak & Canas, 2006) and support reasoning across ontologically different levels (Duncan & Reiser, 2007)
Given list of concepts, but free labels and links	Many students have difficulties distinguishing important concepts in a text, lecture, or other forms of presentation. Part of the reason is that many students learn only to memorize but not distinguish and sort out concepts. They fail to construct propositional frameworks and see learning as "blur of myriad facts, dates, names, equations, or procedural rules to be memorized, especially in science mathematics and history" (Novak & Canas, 2006). Ruiz-Primo (2000) compared concept mapping tasks with varying constraints and found that constructing a map using a given list of concepts (forced choice design) reflected individual student differences in connected understanding better than more constrained fill-the-map forms. Complex topics, such as evolution, consist of a large number of concepts that often make it challenging for novices to identify key concepts. Providing students with a list of expert-selected key concepts can serve as signposts and model expert understanding. Concept maps generated from the same set of concepts allow for better scoring and comparison. Students' alternative concepts are captured in the concept placement, link labels, and link direction. Knowledge integration maps can help students in eliciting relations between concepts, distinguishing central concepts, and making sense of complex science topic such as evolution
Concept map training activity	Students need initial training activities to learn the concept mapping method and generate criteria for concept map critique
Starter map	Building a KIM from scratch can be challenging. Providing a starter map as a partially worked example could reduce anxiety (Czerniak & Haney, 1998). Critiquing and revising concept maps with starter maps require a completion strategy (Chang, Chiao, Chen, & Hsiao, 2000; Sweller, Van Merrienboer & Paas, 1998)
Collaborative concept map activity	KIMs are generated collaboratively in dyads. As each proposition is constrained to only one link, students are required to negotiate which connection to revise or generate. Students are required to generate criteria and negotiate with their partner
Focus question	The domain-specific focus question guides the construction of the KIM as learners select concepts and generate links to answer the focus question (Derbentseva, Safayeni, & Canas, 2007)
Feedback and revision	Feedback and revision support students' knowledge integration through revisiting, reflecting, and revising existing and new concepts. Concept maps often need several revisions to adequately answer the focus question. Kinchin (Kinchin, De-Leij, & Hay, 2005) suggested that generating several new concept maps could support revisiting concepts better than continuously revising one concept map. Starting new maps allows reviewing superordinate structures that otherwise persist without revision
Tools	KIMs can be generated using paper-and-pencil or digital concept mapping tools such as Cmap (Canas, 2004)

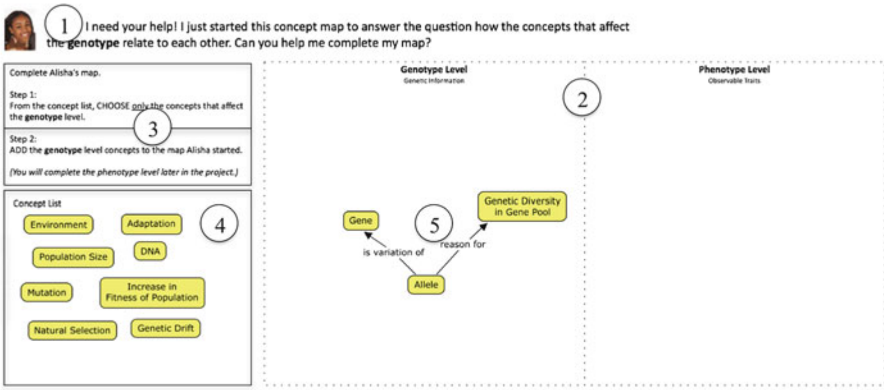


Fig. 2.1 Knowledge integration map worksheet

freely choose their concepts and labels to highly directed tasks where students fill in concepts out of a given list into blanks in a given skeletal network structure (Novak & Canas, 2006). Highly constrained maps can be beneficial for low-performance and younger students, although they provide less insight into students' partial knowledge. Free drawing concept maps provide the most insight but do not allow for standardized comparisons between students. Constraining students by providing them with a set of concepts or link labels allows for standardized or even automated comparison across students on the exact same content but appears to be more challenging for many students than working from memory. They must discipline themselves to use the given concepts rather than to freely follow their thought patterns (Fisher, Wandersee, & Moody, 2000). KIMs aim for a balanced design by providing students with a small set of concepts but allowing them to generate their own connections and labels. This design allows comparing maps of different students with each other. KIM worksheets consist of five elements: (1) focus question, (2) evolution-specific levels (genotype and phenotype), (3) instructions, (4) given list of concepts, and (5) starter map (see Fig. 2.1).

KIM tasks are created through the process: (1) Generate focus question; (2) based on domain-experts and textbooks, identify key concepts for the map that allow answering the focus question adequately; (3) structure concept map into field-specific levels, for example in biology: genotype/phenotype or individual/population; in chemistry: micro/macro/symbolic; (4) create a starter map; (5) create a concept map training activity. KIMs model what experts consider important concepts by providing a list of expert-selected concepts. Kinchin (2000a) noted that the number of given concepts should be kept small (around 10–20) to reduce complexity and time consumption.

Based on an evaluation of major biology textbooks, state standards, and interviews with experts (for a discussion on expertise, see for example Chi, Glaser, & Rees 1982; Schvaneveldt et al. 1985; Scardamalia & Bereiter, 1991; Hoffman, 1998), 11 concepts have been selected for the forced-choice design of the KIM.

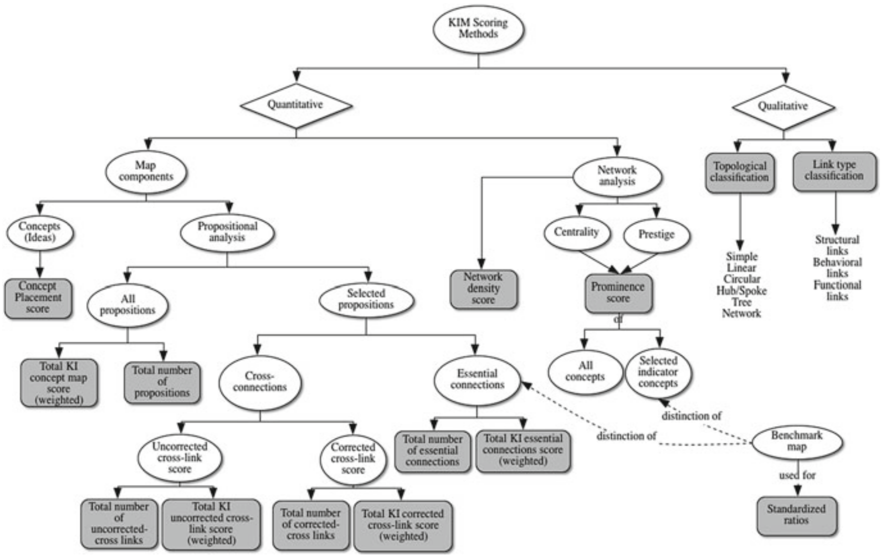


Fig. 2.2 Overview of KIM analysis methods

The number of concepts was kept low in order to keep to size and complexity of the KIM reasonable for the given time constraints for its creation. A total of 55 connections are possible between the given 11 concepts, but not all propositions are of equal importance. (Considering each direction individually and allowing for circular links to same concept, $11 \times 11 = 121$ connections are possible.) Students need to decide which connections are essential to represent their understanding. Additionally, each connection can go in either direction and be described by many different labels. Students need to match the directionality of the connection with the label and construct a label that accurately describes the nature of relations. As the map constrains students to only one connection for each relation, the students need to develop decision-making criteria. Students are free to generate their own links and labels. To model expert understanding, the given list of concepts includes only expert concepts but no alternative concepts such as “need,” “intentionality,” or “want.” Alternative concepts can be expressed through concept placement and link labels.

2.1 Forms of KIM Analysis

Literature indicates that concept map analysis is no trivial task and can use a wide variety of scoring methods (see the following discussion of quantitative and qualitative analysis methods). Concept maps can be analyzed either qualitatively or quantitatively. Figure 2.2 provides an overview of different KIM analysis methods.

2.2 Quantitative Concept Map Analysis

The inclusion of concept maps as large-scale assessment tools, for example those used in the 2009 NAEP exam in science (Ruiz-Primo, Iverson & Yin, 2009), requires economical as well as reliable and valid scoring methods. Several studies reported the validity and reliability of quantitatively evaluating concept maps as assessment tools (for example Ifenthaler, 2010; Markham, Mintzes, & Jones, 1994; Ruiz-Primo, 2000; Ruiz-Primo et al., 2009; Ruiz-Primo, Schultz, Li, & Shavelson, 2001; Ruiz-Primo, Schultz, & Shavelson, 1997; Ruiz-Primo & Shavelson, 1996; Stoddart, Abrams, Gasper, & Canaday, 2000; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005).

Concept maps contain several elements that can be quantitatively evaluated: concepts, hierarchy levels, propositions, and the overall network structure. Links and concepts can be easily counted, but their amount provides little insight into a student's understanding. A higher number of links does not necessarily mean that the student understands the topic better as many links might be invalid or trivial (Austin & Shore, 1995; Herl, 1999). Evaluating the number of hierarchy levels has been suggested by Novak (Novak & Gowin, 1984). The existence of hierarchies is linked to a higher level of expertise, but hierarchy levels can be difficult to differentiate and some concept maps can be non-hierarchical but still valid maps. Propositions, the composite of two concepts, a link label, and an arrow can be evaluated in order to learn about students' understanding. It can be decided to evaluate all propositions equally, to weight certain propositions more than others (Rye & Rubba, 2002), or to analyze only certain indicator propositions (Ruiz-Primo et al., 2009). Yin et al. (2005) showed that scoring each individual proposition on a four-point individual proposition scale, summed up to a "total accuracy score," provided the best validity: 0 for scientifically wrong or irrelevant propositions, 1 for partially incorrect propositions, 2 for correct but scientifically "thin" propositions, and 3 for scientifically correct and strong propositions. The "total accuracy score" allows comparing the overall quality of students' concept maps. The disadvantage of this method is its time consumption, and equal evaluation of links that show deeper understanding and trivial links. Yin et al. (2005) compared the total accuracy score to a second concept map scoring method, the convergence score. Propositions of the students' concept map are compared to an expert-generated benchmark map. The convergence score is the proportion of accurate propositions out of all possible propositions in the benchmark map. Concept maps can contain a large number of rather trivial connections. An alternative to scoring all links is to focus only on a small number of selected links (Yin et al., 2005). Ruiz-Primo et al. (2009) suggest that scoring only essential links is more sensitive to measuring change because it focuses only on the key concepts of the concept map.

However, analyzing only isolated propositions does not account for the network characteristics of a concept map. Quantitative propositional alone could lead to the same score for a list of isolated propositions and a network of the same propositions. Network analysis can be used to describe the connectedness of a KIM's overall density and prominence of selected indicator concepts.

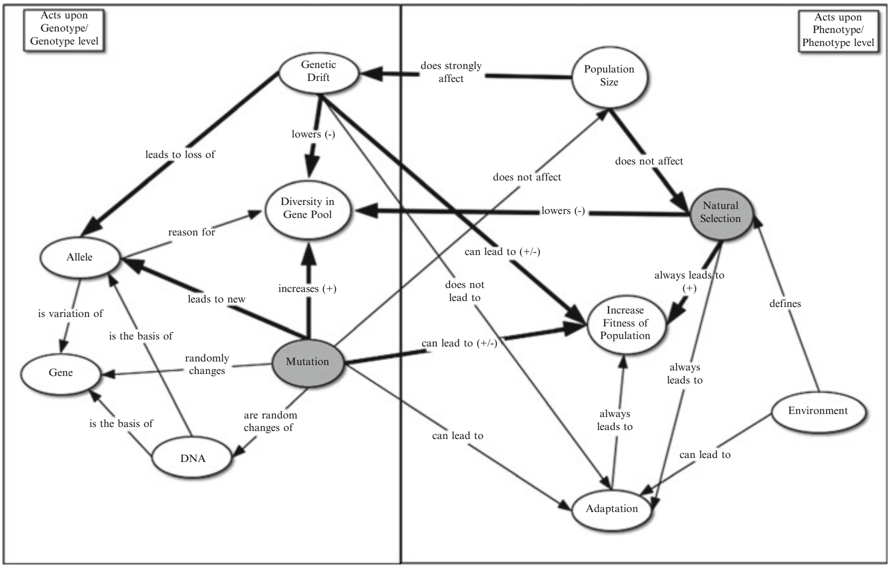


Fig. 2.3 KIM benchmark map. Indicator concepts (*grey*), essential connections (*bold*)

2.2.1 Benchmark KIM

To understand and use concepts, concepts need to be connected to existing concepts. The degree of interconnections between concepts is an essential property of knowledge. One aspect of competence in a field is well-integrated and structured knowledge (Bransford et al., 2000a; Glaser, Chi, & Farr, 1985; Novak & Gowin, 1984). Cognitive psychologists postulate that "the essence of knowledge is structure" (Anderson, 1984, p. 5). An expert-generated KIM can be used to identify the overall structure, central concepts, and essential connections (see Fig. 2.3). However, a benchmark map should not be interpreted and used as the single correct solution but as an expert-generated suggestion that allows identifying central concepts and connections for a detailed analysis. A benchmark KIM can be used to standardize variables to compare different student-generated KIMs against one another. The benchmark KIM indicates how many and which connections experts generate. To calculate standardized KIM variables, student-generated KIM variables are divided by the benchmark KIM variables.

2.2.2 Indicator Concepts

Ruiz-Primo suggested that knowledge within a content field is organized around central concepts, and to be knowledgeable in the field implies a highly integrated conceptual structure (Ruiz-Primo et al., 1997). Graphic organizers can enhance

Table 2.3 Comparison between classical concept maps and KIMs

Classical concept map	Knowledge integration map
No weighted concepts	Weighted concepts (indicator concepts)
No weighted relations	Weighted relations (essential connections)
Hierarchical arrangement of concepts	Non-hierarchical placement of concepts in domain-specific levels

student learning by representing complex concepts in an organized structure reflecting the importance of each concept (Plotnick, 1997; Romance & Vitale, 1999). To reverse this finding, learners' understanding of the importance of concepts can be identified by analyzing how connected selected concepts are in a KIM. For the KIM network analysis, one concept from each level (genotype/phenotype) has been selected as the "indicator concept." Indicator concept analysis describes the number and kind of connections to other concepts. The criteria for selecting indicator concepts were (1) centrality in the expert benchmark KIM (see Fig. 2.3) and (2) importance according to evolutionary theory literature:

- For the genotype level, "mutation" has been identified as the indicator concept.
- For the phenotype level, "natural selection" has been identified as the indicator concept.

2.2.3 Essential Connections

Ruiz-Primo et al. (2009) found that a KIM analysis that focuses on preselected "essential links" instead of all links can reveal a greater variety of maps while being more time efficient. KIM analysis used ten essential connections (see Fig. 2.3). The criteria for selecting the essential connections were (1) connections between the indicator concepts and the newly introduced concept "gene pool" and "genetic drift" and (2) cross-connections between genotype and phenotype levels. An increased number of cross-connections can be interpreted as a more connected understanding of genotype and phenotype concepts.

KIMs differ from classical concept maps in several characteristics (see Table 2.3).

2.2.4 KI-Rubric for Concept Maps

To quantitatively describe changes in KIMs from pretest to posttest, primary and secondary analysis variables were used. Primary variables are based directly on the KIMs, while secondary variables are calculated from primary variables. Primary propositional scoring included (1) scoring of all propositions and (2) scoring of only essential propositions.

Table 2.4 KIM knowledge integration rubric

KI score	Link label quality	Link arrow	Sample propositions
0	None (no connection)	None (no connection)	None
1	Wrong label	Wrong arrow direction	Genetic variability includes mutation
2	No label	Only line	Mutation -- genetic variability
	Correct label	Wrong arrow direction	Genetic variability –contributes to > mutation
	Incorrect label	Correct arrow direction	Mutation – includes > genetic variability
3	No label	Correct arrow direction	Mutation --> Genetic Variability
4	Partially correct label	Correct arrow direction	Mutation – increases -> Genetic Variability
5	Fully correct label	Correct arrow direction	Mutation – causes random changes in the genetic material which in turn increases -> Genetic Variability

1. Score all propositions
   KIM propositions consist of two concepts and their relation (indicated by a labeled line with an arrowhead). Propositions are the elementary units of KIMs. Individual propositions were analyzed using a five-level knowledge integration rubric (see Table 2.4). All propositions were weighted equally.
2. Score only essential propositions
   Using the same five-level knowledge integration rubric (see Table 2.4), only essential propositions were scored (see Fig. 2.3).

2.2.5 Concept Placement Analysis

KIMs ask students to sort out concepts into domain-specific levels (for example genotype and phenotype). Concept placement is an additional level of information that indicates how students categorize concepts. Connecting concepts within a level indicates students' understanding of the relations between closely related concepts. Connecting concepts across levels (cross-links) indicates students' understanding across ontologies and levels of space and time. Cross-links are of particular interest as they can indicate "creative leaps on the part of the knowledge producer" (Novak & Canas, 2006) and reasoning across ontologically different levels (Duncan & Reiser, 2007). Cross-links are relations between concepts in different levels. Cross-connections are of particular interest as they indicate if students see connections between genotype- and phenotype-level concepts. As concepts might be wrongly placed by students, an observed cross-connection might actually be a connection

Table 2.5 KIM primary variables: Number of links

Variable name	Description
Total number of links	Number of links in the KIM
Total number of essential links	Number of essential links in the KIM
Total number of uncorrected cross-links	*Uncorrected* cross-links are connections that cross the line between the genotype and phenotype level. Because of falsely placed concepts, the connection might not be a true cross-connection between a genotype- and phenotype-level concept. However, the uncorrected cross-link can be seen as an indicator for students' motivation to connect concepts across levels
Total number of corrected cross-links	*Corrected* cross-links count connections between genotype- and phenotype-level concepts, even if the concepts were wrongly placed

between two concepts of the same level ("uncorrected cross-link"). To account for such cases, a "corrected cross-link" variable indicates intra-domain connections even if the concepts were wrongly placed.

2.2.6 Primary Analysis Variables

Two different sets of primary variables were created: non-weighted number of links (see Table 2.4) and links weighted by their respective knowledge integration (KI) scores (see Table 2.5).

1. Primary variables: Number of links (see Table 2.5).
   As propositions may differ not only in quantity but also quality, propositions were weighted by multiplying them with their respective KI scores (see Table 2.4).
2. Primary variables: Knowledge integration scores (see Table 2.6).

2.2.7 KIM Secondary Analysis Variables

Another way to describe quantitative changes in KIMs is density variables and ratios (calculated from primary analysis variables). Ratios and densities can be relative or standardized (see Table 2.7).

2.3 KIM Network Analysis

Research suggests that concept maps can assess different forms of knowledge than conventional assessment forms (Ruiz-Primo, 2000; Shavelson, Ruiz-Primo, &

Table 2.6 KIM primary variables

Variable name	Description
Total KI score of all links (total accuracy score)	Product of total number of links and their respective KI scores
KI score essential links	Product of total number of essential links and their respective KI scores
KI score genotype level only	Product of number of links in the genotype-level area (not counting cross-links) and their respective KI scores
KI score phenotype level only	Product of number of links in the phenotype-level area (not counting cross-links) and their respective KI scores
KI score uncorrected cross-connections	Product of number of uncorrected cross-connections and their respective KI scores
KI score corrected cross-connections	Product of number of corrected cross-connections and their respective KI scores

Table 2.7 KIM secondary variables

Variable name	Description
Relative density	Total number of student-generated connections divided by total number of possible connections (=55)
Standardized density	Total number of student-generated connections divided by total number of links in benchmark map (=23)
Relative essential link ratio	Total number of essential student-generated connections divided by total number of student-generated connections
Standardized essential link ratio	Total number of essential student-created connections divided by total number of essential connections in benchmark map (=10)
Corrected cross-connections ratio	Total number of student-generated cross-connections (corrected) divided by total number of cross-connections in benchmark map
KI score ratio	Total KI score in student-generated map divided by total KI score in expert-generated benchmark map (=126)
Standardized KI score ratio	Total KI score of essential connections in student-generated map divided by total KI score of essential connections in benchmark map (=50)

Wiley, 2005; Yin et al., 2005), for example knowledge structure and cross-connections. However, the commonly used quantitative propositional method of analysis does not capture changes in the overall network structure. Network analysis uses the frequency of usage of essential concepts as indicators for a more integrated understanding. The network analysis method is based on social network analysis (Wasserman & Faust, 1994). As students develop a more complex understanding, they might also identify certain concepts as more important and connect them more often. In the KIM example used in this chapter, the indicator concepts “mutation” (genotype level) and “natural selection” have been selected (see Fig. 2.3). Two measurements were used to capture changes in connection frequencies to the indicator concepts.

Network analysis method can identify changes in "centrality" (outgoing connections) and "prestige" (incoming connections) of expert-selected indicator concepts (mutation for genotype level; and natural selection for phenotype level).

- *Centrality*: Outgoing connections from the indicator concept. This variable describes how many relations lead away from the indicator concept.
- *Prestige*: Incoming connections to the indicator concept. This variable describes how many relations from other concepts lead to the indicator concept.

The two network variables centrality and prestige can be combined to a total "prominence score" (importance indicator) for each indicator concept. Multiplied with the KI score for each connection, a "weighted prominence score" for each of the two indicator concepts can be calculated.

An adjacency matrix was used to establish centrality and prestige of each indicator concept. The adjacency matrix, sometimes also called a connection matrix, is a matrix with rows and columns labeled by graph vertices, with a 1 or a 0 in position according to whether two concepts are adjacent or not (Chartrand & Zhang, 2004; Pemmaraju & Skiena, 2003). The expert-generated KIM benchmark was used to determine benchmark values of centrality and prestige.

2.4 Qualitative KIM Analysis

Qualitative analysis methods complement quantitative descriptions of concept maps by tracking changes in the geometrical structure (topology) and types of propositions.

2.4.1 KIM Topological Analysis

Quantitative analysis methods focus only on isolated propositions and therefore cannot give an account of the network character of a whole map. Kinchin (2000b, 2001) suggested a framework of four classes (simple, chain/linear, spoke/hub, net) to describe the major geometrical structure of a concept map. A "network" structure indicates a more integrated understanding than a "fragmented" concept map structure. However, a ranking of these categories is only possible at the extreme ends, with "fragmented" at one end and "networks" at the other. All other classes fall in between. Yin et al. (2005) extended Kinchin's framework by two additional classes (tree and circle) (see Table 2.8):

(0) Simple: Mostly isolated propositions.
(1) Chain: Propositions are in a linear chain.
(2) Tree: Linear chain but with branches.
(3) Hub: Connections emanate from a center concept.
(4) Circular propositions: Propositions are daisy-chained forming a circle.
(5) Network: Complex set of interconnected propositions.

Table 2.8 Concept map topological categories (adapted from Yin et al., 2005)

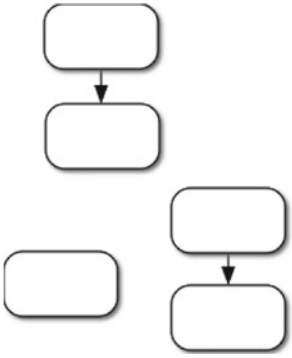
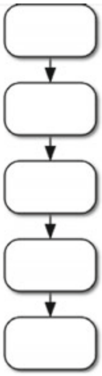
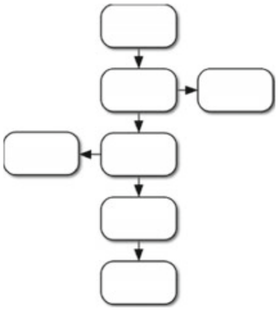
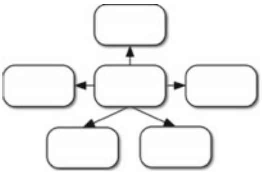
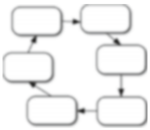
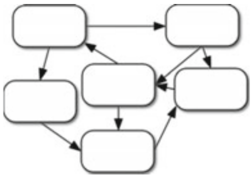
		
Simple/fragmented	Chain/linear	Tree
		
Hub/spoke	Circular	Network

Table 2.9 Topological KIM categories (for a two-area KIM)

First area	Second area
Empty	Empty
Fragmented	Fragmented
Linear	Linear
Tree	Tree
Hub	Hub
Circular	Circular
Network	Network

The analysis methods developed for KIMs further extend Yin's framework. As KIMs are divided into domain-specific levels (for example genotype and phenotype), the geometrical structure of each level needs to be described (see Table 2.9). Coding includes each possible combination of geometrical structures in the two levels. Changes in the topology of KIMs can indicate changes in students' knowledge integration.

2.4.2 Qualitative Proposition-Type Analysis

Learning about relations between concepts is challenging for all learners. When learning a language, students learn nouns before verbs (Gentner, 1978). Typically, KIM concepts are nouns while link labels are verbs. Learning about the relations

Table 2.10 Categories of different types of KIM relations

Super-category	Sub-category	Code	Examples
UNRELATED	No connection	0	
	No label (just line)	1	
	Unrelated label	2	
STRUCTURE What is the structure (in relation to other parts)?	Part–whole (hierarchical)	3	Is a/are a; is a member of; consist of; contains; is part of; made of; composed of; includes; is example of
	Similarity/comparison/contrast	4	Contrasts to; is like; is different than
	Spatial proximity	5	Is adjacent to; is next to; takes place in
	Attribute/property/characteristic (quality (permanent) or state (temporary)	6	Can be in state; is form of
BEHAVIOR What action does it do? How does it work/ influence others?	Causal-deterministic (A always influences B)	7	Contributes to; produces; creates; causes; influences; leads to; effects; depends on; adapts to; changes; makes; results in; forces; codes for; determines
	Causal-probability (modality)	8	Leads to with high/low probability; often/rarely leads to; might/could lead to; sometimes leads to
	Causal-quantified	9	Increases/decreases
	Mechanistic	10	Explains domain-specific mechanism/ adds specific details or intermediary steps
	Procedural-temporal (A happens before B)	11	Next/follows; goes to; undergoes; develops into; based on; transfers to; happens before/during/after; occurs when; forms from
FUNCTION Why is it needed?	Functional	12	Is needed; is required; in order to; is made for
	Teleological	13	Intends to; wants to

between concepts can be more challenging than understanding concepts. However, understanding the relations between concepts is essential to an integrated understanding of biology.

Most existing concept map analyses focus on quantitative variables (see Sect. 2.2). To describe semantic changes in the relations between concepts, qualitative variables are needed. To track changes in relation types, a link label taxonomy has been developed for KIMs (see Table 2.10). The relation categories also include negations, e.g., "does not lead to" or "is not part of."

The concept mapping literature suggests a number of different link types. For example, Fisher (2000) distinguished three main types of propositional relations in biology that are used in 50 % of all instances: *whole/part*, *set/member*, and *characteristic* (p. 204). O'Donnell distinguished between three types of relations in knowledge maps: dynamic, static, and elaboration (O'Donnell, Dansereau, & Hall, 2002). Lambiotte suggested dynamic, static, and instructional relation types for concept maps (Lambiotte, Dansereau, Cross, & Reynolds, 1989). Derbentseva distinguished between static and dynamic relations in concept maps (Derbentseva et al., 2007; Safayeni, Derbentseva, & Canas, 2005).

To create a taxonomy of link types, higher order variables are needed. KIM analysis used the structure–behavior–function (SBF) framework to create the super-categories of the taxonomy. The SBF framework was originally developed by Goel (Goel & Chandrasekaran, 1989; Goel, Rugaber, & Vattam, 2008) to describe complex systems in computer science and then applied to complex biological systems by Hmelo-Silver (Hmelo-Silver, 2004; Hmelo-Silver, Marathe, & Liu, 2007; Liu & Hmelo-Silver, 2009).

- Structure: What is the structure (in relation to other parts)? These variables describe static relations between concepts. Static relations between concepts indicate hierarchies, belongingness, composition, and categorization.
- Behavior: What action does it do? How does it work/influences others? These variables describe the dynamic relations between concepts. Dynamic relations between concepts indicate how one concept changes the quantity, quality, or state of the other concept.
- Function: Why is it needed? These variables describe functional relations between concepts, for example "want" (intentionality) or "need" (teleological).

The sub-categories for the taxonomy emerged from KIM analysis (see Table 2.10). Categorizing link labels allows tracking and describing how connections changed ontologically.

3 Discussion and Implications

This chapter introduced KIMs as a novel form of concept map and illustrated how a combination of qualitative and quantitative analysis methods can provide complementary information to triangulate changes in learners' understanding of complex topics, such as evolution. KIMs can be rich sources for students' alternative ideas. KIMs can contain different forms of information: presence or absence of connections, quality of connections, different types of link labels, different types of networks, and spatial placement of concepts. To account for these different aspects of KIMs, different analysis strategies need to be applied to triangulate changes in understanding of learners. KIMs provide an additional layer of information by structuring the drawing area into domain-specific areas. As a learning tool, the KIM areas aim to support learners' meaningful structuring of concepts by modeling expert understanding. KIMs can be used in different stages of curriculum development and implementation: As curriculum planning tools, KIMs can be used to identify core concepts and essential connections. As learning tools, KIMs can be used for individual or collaborative generation activities. As assessment tools, KIMs can be used to identify alternative concepts, to elicit existing and absent connections (within and across levels), to categorize concepts (by placing them into matching areas), to describe the overall network structure, and to calculate the prominence score of important concepts. This chapter used an example from biology to illustrate KIM generation and analysis; however, KIMs can be implemented in a wide variety of different fields.

Concept maps as assessment tools have been used to track conceptual change in a wide variety of contexts (Edmondson, 2000; Mintzes, Wanderersee & Novak, 2001; Ruiz-Primo, 2000; Ruiz-Primo & Shavelson, 1996). Since 2009, concept maps have been used in addition to traditional assessment tools in standardized large-scale assessments in the US National Assessment of Educational Progress (NAEP) (Ruiz-Primo et al., 2009) to measure changes in conceptual understanding of science concepts. Concept maps can reveal students' knowledge organization by showing connections, clusters of concepts, hierarchical levels, and cross-links between concepts from different levels (Shavelson et al., 2005). Concept map analysis, especially of more constrained forms, has been found to be reliable and valid (Markham et al., 1994; Michael, 1995; Ruiz-Primo et al., 1997, 2001; Rye & Rubba, 2002; Shavelson et al., 2005; Stoddart et al., 2000; Yin et al., 2005). Less constrained forms of concept maps can include many different kinds of concepts and connections. The amorphousness and arbitrariness of structure, mixture of different kinds of concepts (for example physical object, process, abstract construct, property), and different types of links (for example causal, correlational, temporal, part–whole, functional, teleological, mechanical, probabilistic, spatial) can make analysis challenging and time consuming (McClure et al., 1999). This chapter identified several methods and variables, such as KIM cross-links, indicator concepts' prominence scores, weighted essential link scores, network analysis, topological analysis, and qualitative propositional analysis, that can be more efficient and sensitive than scoring each proposition in isolation.

Cross-links can indicate the integration of knowledge across levels or domains. Experts and successful students develop well-differentiated and highly integrated frameworks of related concepts (Chi, Feltovich, & Glaser, 1981; Mintzes, Wandersee, & Novak, 1997; Pearsall, Skipper, & Mintzes, 1997). Cross-links are of special interest as they can indicate creative leaps on the part of the knowledge producer (Novak & Canas, 2006).

Network analysis of indicator concepts describes changes of the centrality and prestige of indicator concepts. Improved understanding of a complex topic can be tracked through an increase in the prominence of indicator concepts. Distinguishing certain concepts as being important can be interpreted as a shift from a surface-level understanding to a higher order understanding.

Concept maps aim to represent only selected important connections as not all possible propositions are equally meaningful. More connections do not necessarily mean a better map and deeper understanding. It is not necessary to generate every possible connection and include every possible concept but be purposefully selective. Similarly, concept map analysis can focus on essential links. Essential links can be identified through expert-generated KIMs. Research (Ruiz-Primo et al., 2009; Schwendimann, 2011a, 2011b) suggests that focusing on weighted essential links can reveal a greater variety of understanding while being more time efficient.

The analysis of isolated propositions does not account for the network character of KIMs. Network density and prominence scores of selected indicator concepts can describe changes in the network structure of KIMs.

The topological structure of a KIM can indicate shifts in learners' knowledge structure. A "network" structure indicates a more integrated understanding than a "fragmented" concept map structure.

Qualitative proposition-type analysis can indicate shifts in learners' understanding. For example in evolution education, a shift in the prominence of normative evolution concepts "mutation" and "natural selection" and a decrease of teleological concepts "need" or "want" can indicate an improved understanding of the mechanism of evolution. More quantified relations can be seen as an indicator for deeper understanding (Derbentseva et al., 2007).

3.1 KIM Analysis and Benchmark Maps

Expert-generated KIM benchmark maps can be used to identify central concepts, indicator concepts, and essential connections and establish comparison variables. However, they should not be seen as the only correct solution for direct comparison as there is no single ideal expert benchmark map. Using expert-generated benchmark maps might suggest that there is only one correct answer (Kinchin, 2000a). From a constructivist perspective, concept maps should reflect the rich variety of students' repertoire of concepts. Using only a single expert-generated as the benchmark for direct comparisons does not allow capturing the many ways ideas can be expressed in concept maps. There is no single "expert map" as experts can generate a wide variety of concept maps (Schwendimann, 2007). Expert maps can strongly differ from one another (Acton, Johnson, & Goldsmith, 1994), even when using a limited number of given concepts, and show great variety. Expert-generated concept maps distinguish themselves not necessarily in quantity but in informed selection of important concepts, higher level clustering of concepts, and meaningful connections. Students might try to find the one "correct answer" for a KIM. Instructors should stress the point that each KIM is unique and that there are many different possible solutions for a good KIM, as even experts in the same field generate KIMs that are different from one another.

This also raises the question of who is considered an expert. There are many different kinds of experts, for example researchers, practitioners, proficient amateurs, and science teachers (Hmelo-Silver et al., 2007). An expert benchmark map can be generated by a single expert (Coleman, 1998), the teacher, or a group of experts (Osmundson, Chung, Herl, & Klein, 1999). Ruiz-Primo et al. (2001) suggest creating an aggregated expert-group map. Interpreting concept map propositions can be difficult as expert and novices might use the same expressions but with different meaning. Ariew (2003) points out that experts can use seemingly nonnormative expressions as "shorthand" for normative concepts, for example a teleological expressions in biology such as "Beavers developed large teeth because they needed to cut trees." More education research is needed to address the "expert problem" by providing better descriptions of what constitutes an expert and distinguishing different types of experts.

This chapter suggests that scoring propositions using a knowledge integration rubric can reveal a greater variety of students' alternative concepts than a direct comparison to an expert-generated benchmark map (for examples of direct comparisons see Chang, Sung, & Chen, 2001; Cline, Brewster, & Fell, 2009; Herl, O'Neil, Chung, Dennis, & Lee, 1997; Rye & Rubba, 2002). The knowledge integration concept map rubric acknowledges different ways concepts can be expressed. It seems easier to construct concept maps than to make sense of them. Analyzing concept maps can be time consuming and cognitively demanding. Efficient analysis methods are needed if concept maps are to become more widely used as summative or as formative real-time assessment tools (Pirnay-Dummer & Ifenthaler, 2010). The analysis methods described in this chapter were developed for human coders. Automated concept map analysis methods aim to complement or replace coding by hand. Simple automated analysis approaches directly match concept maps to a single expert-generated benchmark map. Direct matching approaches are not sensitive to the rich diversity of alternative ways in which ideas can be expressed in concept maps. Recent approaches for automated analysis aim to alleviate this limitation by using the graphical properties of concept maps or by focusing on the frequencies of selected elements in the map. For example, Hoppe, Engler, and Weinbrenner (2012) developed an algorithm to automatically analyze graphical properties of concept maps without the need for an expert-generated concept map for comparison. Evaluating the frequency of certain propositions (Cathcart et al., 2010) or short chains of propositions (Grundspenkis & Strautmane, 2009) allows describing greater variety of alternative ideas than a direct comparison to an expert map.

No single analysis method can capture and track the rich information present in concept maps. This chapter concludes that only using complementary methods in concert allows describing alternative ideas and triangulating changes in concept maps. A comprehensive analysis of concept maps might combine human and automated evaluation using both quantitative and qualitative methods. Further research is needed to more fully and more efficiently make sense of concept maps.

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Chapter 3
Concept Maps for Comprehension and Navigation of Hypertexts

Franck Amadieu and Ladislao Salmerón

Abstract Comprehension and learning with hypertexts are challenging due to the nonlinearity of such digital documents. Processing hypertexts may involve navigation and comprehension problems, leading learners to cognitive overhead. Concept maps have been added to hypertexts to reduce the cognitive requirements of navigation and comprehension. This chapter explores the literature to examine the effects of concept maps on navigation, comprehension, and learning from hypertexts. The literature review aims to elucidate how concept maps may contribute to processing hypertexts and under which conditions. In spite of the variability of concept maps used in hypertexts, some findings converge. Concept maps reduce the cognitive requirements for processing hypertexts. They support outcomes as well as guiding learner navigation. They convey a macrostructure of the semantic relationships between content that supports more coherent navigation and promotes the construction of a mental representation of the information structure of hypertexts. In practice, concept maps are only beneficial for learners with low skills or low prior domain knowledge. Studies have shown that different strategies in processing concept maps may explain a part of the variance in the benefits provided by the concept maps. Processing that occurs early in the learning task yields better comprehension performance. The conclusions lead to recommendations for designing effective concept maps for learning from hypertexts. Further research could be conducted on the online processes by using eye movement recording in order to analyze dynamic processes during learning.

Keywords Comprehension • Concept map • Hypertext • Navigation • Prior knowledge • Skills

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1 Introduction

Digital reading activities are increasing with the development of mobile devices (i.e., smart phones, laptop computers, netbooks, tablets, ipads), wireless access, and expansion of the World Wide Web to Web 2.0. People today are used to searching for information, communicating, comprehending, and learning with numerical devices. Hypertexts represent a large part of the digital reading document corpus. They offer nonlinear interactions with information that allows people to navigate as they wish within an information space. Such freedom is relevant for learners to access specific information or to construct their own reading path according to their interests or needs. However, a hypertext requires readers to determine whether information should be found to fill in possible information gaps and to decide where they have to look for that information (Shapiro & Niederhauser, 2004). Therefore, this may impose new cognitive requirements such as deciding which hyperlink to follow after reading a particular node or knowing the location of particular information (DeStefano & LeFevre, 2007). For readers, a major portion of hypertext comprehension tasks involves construction of their own reading sequence through the hypertext and the integration of information from different locations by establishing semantic relationships between information nodes. This task is challenging because students have to put together pieces of information that were not assembled in a unique and cohesive way by the author, as is usually the case with traditional paper documents.

In sum, comprehension and learning may be hampered by hypertexts that lack navigation guidance. To guide and reduce cognitive requirements, organizational overviews are usually designed. Among organizational overviews, digital knowledge maps (i.e., concept maps) are abundant. For the last 15 years, concept maps have received much interest: Nesbit and Adesope (2006, p.413) "… estimate that more than 500 peer-reviewed articles, most published since 1997, have made substantial reference to the educational application of concept or knowledge maps."

This chapter aims at reviewing the main empirical studies that have been carried out on the effect of concept maps on comprehension and learning from hypertexts in order to understand how and when concept maps are effective in this context. To our knowledge, no literature review or meta-analyses on the effects of concept maps in hypertexts has been previously conducted. Yet, concept maps have been subject to many examinations in research on hypertext learning. Therefore, this chapter extracts from the literature the main effects of concept maps on navigation and learning as a first step and the main circumstances under which concept maps are most efficient as a second. This work leads to educational implications and future research to contribute to the understanding of processes engaged in learning with concept maps.

To select the empirical studies, the database "Web of Science" was consulted in January 2013 respecting the following procedure:

– The search involved the keywords "hypertext" and "map" or "overview" because studies use different terms to refer to concept maps (cognitive map, concept map, map, and overview).

- Because the majority of research on hypertexts has been conducted over the last 15 years and because technologies have evolved, only studies conducted since 1998 were considered.
- The research areas were filtered to focus on those of education and psychology ("education educational research, psychology multidisciplinary, psychology educational, psychology experimental, computer science interdisciplinary applications").
- Sixty-one hits were obtained. Finally, we excluded articles that did not examine the effects of concept maps and articles that did not include a comprehension or a learning task to assess the effectiveness of concept maps in hypertext. As a consequence, several papers only dealing with the effects of concept maps on information searching were excluded. After this step, 24 articles remained.

2 Concept Maps and Theoretical Backgrounds Used in Hypertexts

This section presents the types of concept map usually used and studied in hypertext learning areas. Next, the main theoretical frameworks used in experimental studies on concept maps for hypertexts are discussed.

2.1 Diversity of Concept Maps in Hypertexts

Among the different overview types (e.g., table of contents, matrix, menu), concept maps have been the topic of pronounced interest in the literature on comprehension and learning from hypertexts (e.g., De Jong & van der Hulst, 2002; Ruttun & Macredie, 2012; Salmerón, Baccino, Canas, Madrid, & Fajardo, 2009). A concept map can be defined as a graphic organizer displaying concepts and links (labeled or not; directional or not) which shows semantic relationships between concepts (Nesbit & Adesope, 2006). An example of a concept map is given in Fig. 3.1.

In the hypertexts field, concept maps may be interactive (learners can navigate by clicking on concepts of the map) or static (Bezdan, Kester, & Kirschner, 2013). They may be specific to a short document or designed for a large website. They may be personal (i.e., learners can build up the map) or supplied by the designer (i.e., the map is already built). They may be imposed by designer or teacher (i.e., learners have to process the map) or available if needed (i.e., learners may consult the map if they wish). They may convey a layout level of the hypertext that does not necessarily overlap with the semantic level of the hypertext (Padovani & Lansdale, 2003; Vörös, Rouet, & Pléh, 2011). The maps used in hypertext environments may be spatially oriented (i.e., indicate the location of the pages within the physical space of hypertexts) or semantic oriented (i.e., displaying the pages and their semantic relationships) (Scott & Schwartz, 2007). In the present chapter, only semantic

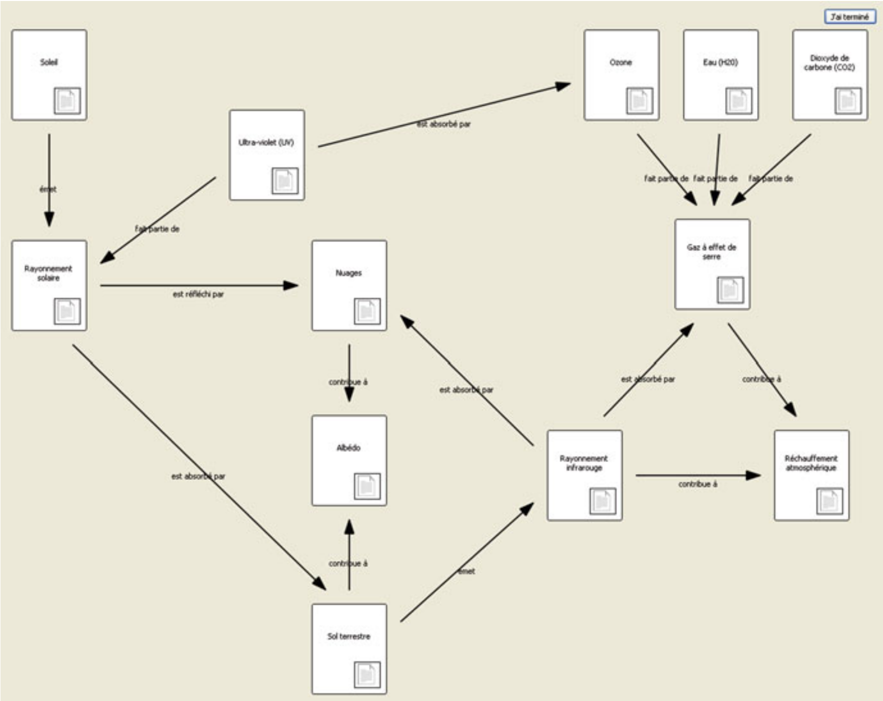

Fig. 3.1 Example of an interactive concept map used in hypertext environments on the greenhouse effect (Amadieu et al., 2012)

organizations are considered because they are usually designed for educational hypertexts. Spatial maps are used more to guide navigation for information seeking in hypertexts. However, overlapping exists between spatial and semantic organizations of maps. The large diversity of concept maps used in hypertexts limits the generalization of findings from research. Nevertheless, some effects seem constant across the different studies. This chapter deals with the most replicated results in the literature.

2.2 Theoretical Frameworks

Different theoretical frameworks have been used to explain how concept maps are linked to textual information during comprehension. This section presents the main theories contributing to investigations on concept mapping and concept maps in hypertexts.

Within the field of concept mapping and the process of associated texts on paper, a concept map is considered as facilitating assimilation of new information. In this way, Mayer (1979) proposed the assimilation encoding hypothesis. Concept maps supply an anchoring structure allowing the encoding of information on the basis of the structure. Another theoretical framework postulates that concept maps would mobilize all the available resources in working memory, as described in the Paivio's (1986) dual-coding model. According to this model, maps would be processed in the visual store while texts would be processed in the verbal store, mobilizing more available resources in working memory. The Schnotz's model (2002) on learning from text and visual displays proposes a more elaborate interpretation of how texts and concept maps are jointly processed. Texts are processed verbally and a propositional representation is constructed, while depictive (graphic-based) information is perceived visually and an internal visual image is constructed. The two mental models share information and influence each other. Thereby, concept maps would lead learners to construct a mental model that would contribute to the conceptual organization of information in memory and to the propositional representation built from the texts.

However, studies examining the effect of concept maps on comprehension and learning from hypertexts call upon other theoretical frameworks. The most frequently used theories come from the text comprehension field or the research field in education.

The construction-integration model (Kintsch, 1988) distinguishes text-based representation (i.e., representation based on explicit information appearing in texts) from the situation model (i.e., representation including information from text and the readers' knowledge base). While text-based representation requires coherent processing cycles of text information, the situation model requires prior domain knowledge to establish coherence between different text parts inferring connection between pieces of information. The second level of representation implies deeper processing. In addition, the model integrates two levels of the text structure, the microstructure (micro-propositional level) and the macrostructure that refers to the processing of the main information and their organization within a text. This second level is clearly the most important for investigating the effects of concept maps on comprehension because they display the macrostructure of hypertexts.

Cognitive load theory may also contribute to a study of hypertext comprehension by describing different levels of task that might support or hamper learning processes (e.g., Amadieu, van Gog, Paas, Tricot, & Mariné, 2009; DeStefano & LeFevre, 2007; Gerjets & Scheiter, 2003). The theory puts forward three types of cognitive load imposed by a learning task (Sweller, Van Merrienboer, & Paas, 1998): (a) the intrinsic cognitive load (related to the number of information elements and the level of element interactivity inherent in the task), (b) the extraneous cognitive load (the load created by the instructional design that does not contribute to learning), and (c) the germane cognitive load (the load spent directly on learning). To be most effective, an instructional design has to reduce extraneous cognitive load and promote germane cognitive load.

While the Mayer's model is specific to the overviews in learning from texts, the other models are more general—describing comprehension and learning processes for different learning material. All of them share the principle of limited working memory resources. Concept maps allow for mobilization of more resources in working memory, and they help to process incoming information supporting the connections between the information pieces. A point of differentiation is that the cognitive load theory is more oriented towards the cognitive capacities of learners, whereas the construction-integration model sheds light on the online processes engaged in comprehension (i.e., how coherence of information is processed and elaborated by learners during their navigation). These models are complementary and can be chosen according to the focus of the research.

3 Functions and Criteria of Effective Concept Maps to Support Learning from Hypertexts

In the hypertexts research field, two main types of guidance have been examined over the last 25 years. The first type reduces the navigation freedom of users by reducing the number of choices in navigation (i.e., limiting the number of hyperlinks from one page). It also constrains the pathways (i.e., the designer imposes a navigation scenario that is consistent with the task or the users' needs), which increases learning performance or efficiency (Gay, 1986; Lee & Lee, 1991; Recker & Pirolli, 1995). The second type of guidance received much attention as it respects to a greater extent the principle of hypertext reading, that is to say nonlinear reading/navigation. This type of guidance is the external representation of the spatial and/or semantic structure of the hypertext represented by concept maps.

In more traditional studies about learning from printed texts, a meta-analysis conducted by Nesbit and Adesope (2006) concluded that studying concept maps exerts a positive effect on learning and can support more efficient learning than studying lists of concepts or outlines. However, the effect sizes remain low, and more investigation of the processes of the reading and use of concept maps (online data) is required. In the hypertext research area, concept maps may also support learning and comprehension. In contrast to the body of research on learning with printed documents, the research literature on hypertext provides researchers with a resource that relies on the recording of online processing (i.e., navigation, processing time, interaction data). These methods provide online data that reflect how students use concept maps and how they impact students' learning. Overall, some studies have investigated the effect of the availability of a concept map in hypertexts (concept map vs. no-concept map), while others have focused on the effects of the type of structure of concept maps. The current section presents the different effects of concept maps on comprehension and learning.

3.1 Concept Maps as Content Overviews Supporting the Organization of Mental Representations

Hypertext comprehension demands that readers process the hypertext semantic structure. Readers must construct a mental representation of hypertext structure that includes both a physical structure of the document (i.e., artifact representation) and a semantic representation (i.e., what is conveyed by the artifact) (Payne & Reader, 2006). A hypertext with a concept map supports better learner performance than a hypertext without a concept map (Scott & Schwartz, 2007). A concept map plays the role of an organizational framework supporting encoding, storing, and retrieving of text content in memory. Naumann, Richter, Flender, Christmann, and Groeben (2007) attested that hypertext-specific signals like concept maps enable learners to select and organize contents more efficiently in hypertexts.

Concept maps facilitate organization of the mental representation of texts (e.g., De Jong & van der Hulst, 2002; Salmerón & García, 2011). This function of concept maps is important to help learners process information distributed in hypertexts displaying main information and its organization. Mental representations of a hypertext contribute to encoding and integrating information. The mental representation of the hypertext semantic structure is similar to a representation of the hypertext macrostructure (Potelle & Rouet, 2003). Concept maps help readers by supporting the inference construction needed to process hypertext structure through the presentation of the hypertext macrostructure. In addition concept maps may promote deeper comprehension. Puntambekar and Goldstein (2007) showed that a navigational overview improved inferential understanding in comparison with organization by list. Trumpower and Goldsmith (2004) corroborated a positive effect on the transfer of expert-structured maps in comparison with maps that were structured randomly and alphabetically. An experiment conducted by Gurlitt and Renkl (2009) also indicated the advantage of a high-coherence map (provided map) in contrast to a low-coherence map (map without links) on learning outcomes with a hypertext.

In spite of many results in favor of concept maps, some results suggest that a concept map can be ineffective for learning. Hofman and van Oostendorp (1999) observed a negative effect of a concept map compared to a list of concepts (i.e., no map) on the construction of the microstructure (i.e., structure of the local relationships between hypertext ideas). Concept maps could detract attention from building local inferences to construct more global relationships. Similarly, Vörös et al. (2011) did not observe any effect of a concept map on comprehension scores compared to an organization by list or a lack of navigation aid. Nevertheless, they found that a concept map displaying the layout of a hypertext supported a mental representation of spatial knowledge (i.e., encoding links and page places). The study also showed that readers tend to encode hypertext structure more from the overview organization than from the embedded link organization. For instance, readers reproduced a list order rather than link structure if they were in a list overview situation. In sum, a concept map may promote the construction of a coherent mental representation of hypertext content or the hypertext structure which can differ from the semantic organization of the hypertext's content. Nilsson and Mayer (2002) conducted an experiment that showed that while a concept map was helpful in navigating a website, the lack of concept map was related to better learning scores. According to the authors, map-based navigation strategies for answering questions were efficient but required no further elaboration for learning.

Examination of the effect of concept maps on mental representations (type and organization) is helpful in understanding their provision for comprehension and learning from hypertexts, but investigation of strategies and online processing is needed to elucidate how learners process and benefit from concept maps.

3.2 Concept Maps Reduce the Navigation Requirements While Guiding Learners Within the Semantic Space

Comprehension and learning from hypertexts require at least two types of cognitive task. On the one hand, learners have to process the semantic contents (constructing meaning from the texts and understanding the conceptual relationships between the texts). On the other hand, they have to navigate within the hypertext (knowing his/her position within the hypertext, selecting links, following pathways relevant to the goals of the learning task). Ideally, the navigation task should support the learning task, but many authors point out the cognitive cost imposed by navigation in hypertexts (e.g., Amadieu & Tricot, 2006, DeStefano & LeFevre, 2007). The limited capacities of working memory imply a limitation of the cognitive cost of the navigation task. The design of hypertext should avoid the navigation task challenging learners.

The adjunction of concept maps is expected to reduce the processing required for navigation and also to guide learners towards relevant processing for the learning task. Some studies confirm the effect of concept maps on navigation, showing that they help users to navigate more efficiently according to the goals of their tasks such as information-seeking (Danielson, 2002) as well as learning (Puntambekar & Goldstein, 2007; Shapiro, 1999). For instance, Puntambekar and Goldstein (2007) observed that concept maps led learners to visit sections more relevant to their objectives.

If hypertext structures have a low complexity, that is to say, structures with symmetry features (e.g., hierarchical structure), learner navigation tends to be guided by the structure (Amadieu, Tricot, & Mariné, 2009a; Salmerón, Cañas, Kintsch, & Fajardo, 2005; Shapiro, 1999). Such navigation is less demanding because the requirement of decision making is low. When concept maps convey structures highlighting the categories or the topics of the hypertexts, readers construct their navigation on the basis of the concept maps' structures. They tend to follow in a systematic way the structure proposed by the concept map (Amadieu et al., 2009a). Shapiro (1999) showed that navigating within a hypertext is based on following the hierarchical structure (participants tend to explore a category once on a level of hierarchy). In sum, navigation is clearly supported by the concept map structures which display content categories to guide learners towards a topic-oriented navigation strategy. Interestingly, when navigation is restricted in a hierarchical concept map, for example by only allowing jumping to the adjacent nodes in the hierarchy, comprehension is hampered and extraneous cognitive load is increased as compared to an unrestricted map (Bezdan et al., 2013). This result suggests that dynamic concept maps represent an efficient trade-off between navigation freedom to adapt to student demands and navigation support to prevent disorientation.

Reader processing cycles of hypertext content may be hampered if navigation does not support coherent reading pathways (Kintsch, 1988), that is to say the reading pathways do not respect the semantic relationships between the hypertext's processed nodes. For instance, it has been shown that a nonlinear presentation of information may hamper processing of content if the contents respect a coherent linear organization like a narrative text structure (Zumbach & Mohraz, 2008). Conversely, navigation based on maintaining semantic coherence between the hypertexts' nodes improves deep comprehension of the contents (e.g., Madrid, Van Oostendorp, & PuertaMelguizo, 2009; Salmerón et al., 2005). Concept maps might play the role of navigational tools, helping readers navigate within a coherent document such as an article (Cuddihy & Spyridakis, 2012). Indeed, by highlighting the semantic structural information (in contrast to a network structure), concept maps help learner orientation within the semantic space of hypertexts yielding more coherent reading pathways (Amadieu et al., 2009a; Amadieu, Tricot, & Mariné, 2010). Concept maps would be mainly useful when navigation or maintaining coherence is demanding. Britt, Rouet, and Perfetti (1996) showed that when the organization of a hypertextual document is random, readers used a table of contents more than direct links between the text sections of the document. The table of contents might have helped readers to establish global coherence of the hypertextual document. The high-level structure conveyed by the table of contents is useful when the semantic relationships between sections are few (see also Salmerón, Gil, Bråten, & Strømsø, 2010).

Hence, hierarchical concept maps would reduce the disorientation that is an important issue in hypertext reading (DeStefano & LeFevre, 2007). Only a few studies assessed disorientation (subjective measures) or cognitive load linked to navigation tasks (subjective measures). McDonald and Stevenson (1998) showed a lower feeling of disorientation caused by a map in contrast to a list of concepts or to a hypertext without a map. Müller-Kalthoff and Möller (2003) showed that a concept map used as a navigation map limited the perceived disorientation of the readers. Similar results have been found by the authors (Müller-Kalthoff & Möller, 2006) comparing different types of concept map structures. Amadieu et al. (2009, 2010) and Patel, Drury, and Shalin (1998) have also shown that disorientation is reduced by a hierarchical structure. However, some studies did not observe any effect of concept map structures (linear, hierarchical, and hierarchical with cross-links) on perceived difficulty (Calisir, Eryazici, & Lehto, 2008; Calisir & Gurel, 2003).

To conclude, concept maps lead learners to follow navigation strategies enabling them to maintain coherence and to explore relevant topics or pages for the task. As a consequence of guided navigation, comprehension and learning performance are supported, particularly for students with low prior knowledge of the topic (Amadieu et al., 2009a; Madrid et al., 2009; Salmerón et al., 2005; Salmerón, Kintsch, & Cañas, 2006).

4 Conditions Under Which Concept Maps Are Effective

The following section presents findings that highlight different effects of concept maps depending on the type of map structure, type of engagement with the learning task, and learners' individual differences.

4.1 Concept Maps Should Convey Semantic Organization of Hypertext Content

As discussed in previous sections, maps can support learning and navigation in hypertexts. Nevertheless, all types of map are not effective, and different processing strategies of maps may impact the quality of subsequent learning. Concept maps should display a coherent semantic organization of hypertext content (e.g., Gurlitt & Renkl, 2009; Trumpower & Goldsmith, 2004). McDonald and Stevenson (1999) showed that a concept map would support learning scores, while a spatial map would only favor more efficient navigation. Learning tasks from hypertext require much processing of semantic characteristics of contents rather than the spatial or the physical features of hypertexts. Even when no cluster organization is provided in a hypertext, students would try to extract the meaning and the conceptual organization of the hypertext's contents (Shapiro, 1999). Concept maps favor the construction of a semantic mental model of hypertext rather than a spatial representation of the document (Farris, Jones, & Elgin, 2002). Therefore, the quality of a concept map depends on the semantic relationships the structure denotes.

This distinction between a conceptual and a physical dimension of hypertexts is also observed in the study of disorientation. Cress and Knabel (2003) proposed consideration of two forms of disorientation: (a) structural disorientation relative to the physical space (learners do not know where they are, how the hypertext is organized, how to access a specific location …) and (b) conceptual disorientation (learners do not know how to relate semantically different concepts from the hypertexts' nodes). Although physical maps may reduce structural disorientation and support the construction of a mental representation of the physical space (Vörös et al., 2011), the concept map should mainly reduce the learners' conceptual disorientation (Amadieu et al., 2010) helping them to identify and interrelate main ideas from a hypertext. Actually, different types of structure have been examined in the literature showing different effects on disorientation and learning.

4.2 Hierarchical Structures Are More Effective than Network Structures

Hypertexts are classically based on interconnected organizations (i.e., network structure). Concept maps promote a structure of contents that should limit cognitive demands and guide the processing of contents. Authors addressed the effects of the types of structure displayed by concept maps to understand which kind of map organization is most suitable for learners (e.g., Amadieu et al., 2009a; Calisir & Gurel, 2003; Potelle & Rouet, 2003). Hierarchical structures are the types which received considerable attention. In contrast to network structures (more representative of classical hypertext structures), hierarchical structures lead learners to consult the hypertexts' contents in a systematic way (i.e., exploring topic after topic) enabling a coherent reading order of the contents (Amadieu et al., 2009a, 2010) and to identify and integrate macro information (Potelle & Rouet, 2003).

Potelle and Rouet (2003) found a positive effect of a hierarchical concept map on comprehension of macro information compared with a network structure for both explicit and implicit information. Amadieu et al. (2009) compared two types of map structure: a hierarchical structure and a network structure (concepts were randomly organized on screen, but semantic links between concepts were displayed). The results confirmed a positive effect of the hierarchical structure on the situation model. Many other studies confirmed a positive effect of hierarchical maps (Calisir & Gurel, 2003; Shin, Schallert, & Savenye, 1994). It is worth noting the findings that hierarchical hypertexts did not yield higher learning performance, neither did they hinder it (e.g., Calisir et al., 2008).

4.3 Processing Concept Maps Early During the Learning Task

Processing contents from hypertexts is a dynamic and autoregulated task. Learners are free to navigate and read information at their own pace. In the same way, processing concept maps is regulated by learners and varies with the learners' strategies. Salmerón and colleagues carried out studies addressing this question. Their findings show a positive effect of the early processing of concept maps on performance. Indeed, concept maps appear to be effective when students look at them at the beginning of a learning task, as informed by students' eye movements (Salmerón et al., 2009). These findings have also been replicated by Salmerón and García (2011) for younger learners (11-year-old students), suggesting that this type of strategy is effective for learners with different abilities.

In sum, devoting processing time to the concept map early in the learning task enables learners to construct a mental representation of the information structure that helps them to integrate the main ideas throughout the task. These findings are consistent with findings coming from the research field on learning from texts (Lorch & Lorch, 1996; Mayer, 1979). Nevertheless the influence of the initial processing of concept maps on reading strategies has to be proved. Results obtained by Salmerón and García (2011) did not confirm an effect of the initial processing of maps on the level of coherence of hyperlinking navigation.

The conclusions of these different studies highlight the need to consider how concept maps are used in order to explain the observed variance of their effects on learning. Therefore, the examination of concept maps as a tool for learning from hypertexts also requires investigation of the factors behind such variance.

But do use strategies depend on individual differences? The following section sheds light on the main individual differences that would explain variability in the efficiency and use of concept maps.

4.4 Individual Differences and Concept Maps

In spite of numerous studies showing the positive effects of concept maps in learning from hypertexts, criteria and conditions are required to improve efficiency of concept maps. Their effectiveness may depend on students' behavior and abilities, with individual differences strongly moderating the effect of such maps.

4.4.1 Prior Domain Knowledge

The individual difference that generated the most interest in the literature on learning from hypertexts is the student's knowledge base about the content domain. Prior domain knowledge provides resources to cope with the cognitive requirements to process hypertexts (for a literature review see Amadieu, Tricot, & Mariné, 2011).

As far as the comprehension and learning performance in hypertexts are concerned, prior domain knowledge can support deep comprehension reflected by the situation model (Müller-Kalthoff & Möller, 2004; Shapiro, 1999) as well as shallow comprehension reflected by the text-based representation (Müller-Kalthoff & Möller, 2006). Taking into account the variable prior domain knowledge provided interesting evidence to interpret varying effects of concept maps on learning. Numerous studies concluded that concept maps or their types of structure would impact learning outcomes mainly for low-prior-knowledge learners because they lack cognitive resources to process the semantic organization of information (e.g., Potelle & Rouet, 2003; Shapiro, 1999). In fact, while some studies indicate that hierarchical maps can help low- as well as high-prior-knowledge learners (e.g., Patel et al. 1998), others show that the positive effect of concept maps vanishes for high-prior-knowledge learners. For instance, Amadieu et al. (2009a) observed the main effect of prior knowledge on deep comprehension (inference questions about the relationships between the hypertext's concepts) and showed that a hierarchical structure supported free recall performance only for low-prior-knowledge learners.

Findings explain how prior knowledge supports learning in hypertext without concept maps or with maps displaying a network structure. Prior knowledge guides navigation, supporting more coherent reading pathways (Amadieu et al., 2009a, 2010). However, Salmerón and colleagues (2005, 2006) showed that prior knowledge helps learners to cope with disruption of coherence in navigation. They observed that low coherent reading orders guided by an overview (matrix) of a hypertext lead high-prior-knowledge readers to higher comprehension than coherent reading orders. The reverse was observed for low-prior-knowledge readers. The results highlight a deeper processing of content promoted by disruption between the concepts in navigation thanks to prior knowledge.

To sum up, concept maps are either not or less effective for high-prior-knowledge readers because their knowledge base is an adequate resource to process the main ideas from a hypertext and their relationships and to establish elaborative inferences if the coherence of reading orders (navigation) is low. However, it is worth noting that a lack of concept maps or maps displaying network organization does not promote deeper processing for high-prior-knowledge learners; thereby it does not increase their level of learning.

In conclusion, prior domain knowledge is one of the main resources for learners to cope with the processing demands of hypertext. It can guide learner navigation as well as help learners to infer implicit relationships between concepts from hypertext content. Nevertheless, other abilities contribute to comprehension and learning from hypertexts. The following section presents the main abilities that have received attention in the previous decade.

4.4.2 Other Abilities

In addition to prior domain knowledge, other individual differences are examined in the studies on hypertexts. The findings stressed that the effects of concept maps should be considered in the light of these individual differences.

Reading skills that are classically examined in the research field on learning from texts are increasingly examined in the studies on learning from hypertexts with concept maps. Studies conducted by Naumann et al. (2007) indicated that reading skills enable learners to succeed independently of the organizational signal such as concept maps, whereas learners with a low level of skills benefit from hypertexts with organizational signals. Salmerón and García (2011) found that reading skills support higher comprehension (inference questions) in a hierarchical map used for navigation. More interestingly, the authors validated a mediation model explaining how reading skills support deep comprehension with an interactive map. Reading skills exerted a positive effect on the use of a cohesive hyperlink strategy, that is to say that high-reading-skill learners follow reading paths within the hypertext characterized by a high semantic relationship between the hypertext nodes. The consequence is a deeper comprehension of the hypertext.

As processing hypertext may imply processing of spatial dimension, particularly for navigating, the learners' spatial abilities would participate in handling hypertexts by encoding the hypertext structure (Rouet, Vörös, & Pléh, 2012). Vörös, Rouet, and Pléh (2009) corroborated an effect of concept maps moderated by the level of visuospatial memory capacity. A concept map appeared more helpful for navigation for the low-spatial-memory participants. The concept map acted as an external memory that eliminated the differences between high and low visual memory capacities observed in a situation without a map. The results also indicated that a map was more useful when the hypertexts were more complex.

Scott & Schwartz (2007) showed that while a spatial map (simpler map) is more efficient for learning (free recall, essay) for learners with low metacognitive skills than for learners with high metacognitive skills, a spatial and semantic map is more beneficial for the latter learners than for the former. Processing a map combining spatial information and semantic relationships between pages of a hypertext is supported by metacognitive skills.

More recently, a study (Salmerón & García, 2012) shed light on the effects of sustained attention abilities. The results indicated that a hierarchical concept map was useful for students with low sustained-attention skills. This result concurs with the previous studies on the moderating effect of learner skills.

To conclude, different sorts of abilities (prior knowledge, reading skills, spatial abilities) may determine the level of contribution of concept maps to learning. On the one hand, when learners present low abilities, concept maps are tools that support comprehension and learning from hypertext, limiting the cognitive requirements and guiding learning to relevant processes for the learning task. Furthermore, adding a concept map to a hypertext may reduce the gap between participants in terms of disorientation and learning. On the other hand, when learners present high abilities, concept maps are less useful because the learners are able to cope with the lack of visual overview of the content structure using a better navigation strategy and applying better comprehension processing.

5 Discussion and Conclusion

Findings from the studies on comprehension and learning concur about the positive effect of concept maps on performance. Concept maps are overviews displaying the main concepts of hypertext content and semantic relationships between the concepts. Highlighting the semantic organization of hypertexts, they support the construction of a mental representation of the information explicitly mentioned in hypertexts as well as implicit information relative to connections between information nodes. Concept maps are mainly useful for understanding the macrostructural level rather than the microstructural level. This finding concurs with the results observed on concept maps in more traditional documents (Nesbit & Adesope, 2006). To be effective, concept maps should convey a semantic organization of hypertexts rather than a physical/spatial organization. That is consistent with a congruence principle between the displayed structure and the knowledge domain structure (Tversky, Bauer-Morrison, & Bétrancourt, 2002). The beneficial effects of concept maps also apply to orientation or navigation within hypertexts. They guide the selection of links maintaining a better coherence between the read information nodes. A lack of concept maps may lead learners to higher disorientation. In sum, concept maps support the processing of hypertexts by limiting the cognitive requirements of a learning task with that hypertext.

However, many studies have shown that the effects of concept maps depend on their features and on learner skills. The nature of the structure plays a main role. Concept maps displaying a hierarchical structure yield better learning. Concept maps with more interconnections between the concepts may be very demanding. The hierarchical structure is easier to process because its mental representation can be maintained in the working memory with less effort. When no concept map is provided or when concept maps are quite complex (i.e., concept maps with a network structure), the learners' prior knowledge and skills help them to process the hypertext and to reach performance as high as when a concept map is provided or when a concept map is quite simple (i.e., hierarchical structure). Concept maps can compensate for learners with low abilities.

Recent research also highlights processing strategies for concept maps that explain individual differences regarding their effects. Early processing of a concept map in the learning task leads to higher learning performance. Concept maps are more effective if learners construct a first mental representation of content organization at the beginning to then process the incoming information throughout the learning task. Concept maps play the role of scaffolding to support the processing of hypertexts. Overall, the conditions for efficient concept maps in hypertext environments are consistent with some of Mayer's recommendations (1989) to design an overview of conceptual models: the learners should have low prior knowledge, and the model should be concise (describing only the main information) and coherent and should be given before and during a lesson.

5.1 Educational Implications

The results presented in this chapter concur with the need to include concept maps in instructional hypertexts. However, designing effective concept maps for learning in hypertextual environments should respect some principles derived from our review of the literature.

First, because learners tend to construct a mental representation of the hypertext structure from concept maps rather than a link structure of the hypertext, concept maps should match with the link structure or at least should not be inconsistent with it (Trumpower & Goldsmith, 2004; Vörös et al., 2011).

Second, concept maps must allow students to freely select the pages they want to visit while providing a reference for the structure of the hypertext to prevent disorientation (Bezdan et al., 2013).

Third, it seems necessary to take into account the different strategies of reading and processing of concept maps. The differences between learners may be numerous. Learners use concept maps in different ways.

Fourth, it would seem preferable to train students to process concept maps because some processing strategies are more efficient than others (i.e., processing maps early in the learning task).

Fifth, maps should be adapted to the students' prior knowledge and skills. To maximize the effects of concept maps, teachers and designers of pedagogical hypertexts should consider the compatibility between the concept maps and the learners' characteristics and habits.

5.2 Further Research

Although some findings about the effects of concept maps on learning from hypertexts converge, more investigations need to be carried out on the online processing of concept maps and on the conditions that increase their positive effects. The diversity of the methods (material, measures, tasks, knowledge domain …) used in the different studies limits their comparison. For instance, in these studies the concept maps are not always described in detail and can be quite different (extent, number of concepts, number of links, links labels or no label, interactive or not …). Le Bigot and Rouet (2007) showed that a source-based list of a hypertext content improves macrostructural comprehension of multiple documents, whereas a topic-based list supports microstructural comprehension. Hence, the labels used in concept maps may be determinant in the processing of hypertext contents.

To proceed in examining the features of concept maps and the associated processes, online recording methods are required. The development of techniques such as eye movement recording offers good opportunities (e.g., Amadieu et al., 2009; Salmerón et al., 2009). Moreover, the recording of map reading time over a learning session is crucial to examine the dynamic aspects of the learning task with concept maps. The processing strategies for concept maps that support comprehension and that orient navigational behaviors in hypertexts have still to be studied.

Next, more examination of the mental representations of maps should be conducted. Most of the studies measured comprehension or learning performances related to the contents. Only a few studies considered the organization of the mental representation of the map or of the hypertext (e.g., Vörös et al., 2011).

Increasing the number of studies dealing with individual differences should help the understanding of processing and the cognitive requirements of learning from hypertexts and should guide the design of concept maps that fit with learner needs. New individual differences should be considered such as motivation (Moos & Marroquin, 2010) or working memory span (Naumann, Richter, Christmann, & Groeben, 2008) that can impact learning and the use of hypertexts. In summary, future studies should continue to investigate the moderating effects (individual differences) as well as the mediating effects (online processes related to concept maps) implied in learning from hypertexts with concept maps.

In addition to the study of concept maps provided by designers, new research has been investigating concept mapping in hypertexts in recent years (e.g., Amadieu et al. 2012; Amadieu, Tricot, & Mariné, 2009b; Gurlitt & Renkl, 2009). As concept mapping consists of building a concept map by learners, it offers new opportunities for studying how learners construct a mental representation from hypertext contents. Although concept mapping seems less effective for learning in comparison with fixed concept maps (Amadieu et al., 2012; Gurlitt & Renkl, 2009), it contributes to understanding the cognitive requirements of hypertext processing. It can be supposed that imposed concept maps would not be positive for all learning from hypertext. For instance, Kester and Kirschner (2009) showed that fading support by presenting less and less detailed concept maps can promote more accurate navigation for learners even if no effect on learning was observed in their study.

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Chapter 4
Using Digital Knowledge Maps for Supporting Tutors Giving Effective Explanations

Andreas Lachner and Matthias Nückles

Abstract Explanations of expert tutors have shown to be superior compared to explanations of student tutors regarding students' transfer of learning. However, there is little evidence which expertise-related features of explanations account for students' processing and learning. In this chapter, we present a knowledge mapping approach for analyzing expertise-related features of explanations. Therefore, we used graph-oriented measures that take the explanatory structure into account. We conducted a series of experiments testing this knowledge mapping approach: First, our measures demonstrated to be able to detect expertise-related features of explanations, such as conciseness and coherence. Second, we could show that our measures both predicted students' learning outcomes and learning processes, thus indicating the validity of our measures. Additionally, we discuss how our knowledge mapping approach could be used as a self-awareness tool for supporting tutors in giving coherent explanations. To increase the effectiveness of instructional explanations, our knowledge mapping approach could be a promising means for guiding tutors while writing instructional explanations.

Keywords Instructional explanations • Tutoring • Transfer of knowledge • Graph theory • Assessment

1 Introduction

Instructional explanations can be useful in a wide range of teaching settings, such as tutoring (Chi, Siler, & Jeong, 2004), classroom teaching (Ma, 2010), or university teaching (Bligh, 1998; Hinds, Patterson, & Pfeffer, 2001). Instructional explanations

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are used as a prevalent instructional method to introduce students into a new subject domain, to engage students deepening and elaborating their conceptual knowledge, or supporting students when they get stuck (Berthold, 2012). However, instructional explanations often do not promote learning (Wittwer & Renkl, 2008). First, one of the pitfalls of instructional explanations is that they often are poorly adapted to students' informational needs (Nückles, Wittwer, & Renkl, 2005; Wittwer, Nückles, & Renkl, 2010). They often do not build upon learners' prior knowledge, which would enable the learners to integrate the newly presented information into their existing prior knowledge. A second drawback is that instructional explanations often do not engage students in deeply processing the presented contents (Berthold, 2012). Thus, students often simply repeat segments of the instructional explanations, which are less likely to promote a deep understanding of the subject matter. As empirical research on expert-novice communication has shown, advanced students with less teaching expertise in particular might face problems in giving effective explanations that promote students' construction of flexible and transferable knowledge (Hinds et al., 2001).

In order to support student tutors in giving effective explanations, we developed an assessment approach that analyses beneficial structural features of explanations. Specifically, we used a knowledge mapping approach that takes instructional explanations as input and revisualizes the instructional explanations as knowledge maps through propositional segmentation (Patel & Groen, 1986). Through the revisualization of an instructional explanation, its underlying structure becomes salient and can be analyzed mathematically by structural measures derived from graph theory (Sowa & Shapiro, 2006).

The chapter has five sections: as student tutors may face difficulties in generating effective explanations, in the first section, we review empirical research that investigates differences between expert tutors and student tutors regarding the effectiveness of their explanations for students' learning. In order to illuminate advantageous textual features of instructional explanations, we review, in the second section, research regarding the effective design of instructional explanations. In the third section, we present a knowledge mapping approach to assess tutors' instructional explanations by analyzing structural features that enable students to deeply process the explanations. In the fourth section, we provide evidence for the effectiveness and validity of our knowledge mapping measures with regard to students' knowledge acquisition and their processing of the explanations. Based on this research, in the fifth section we outline how our approach to knowledge mapping may be further developed in order to be used by tutors as a self-awareness tool that may support them in producing effective instructional explanations.

2 Tutors' Expertise and the Effectiveness of Instructional Explanations

Prior research suggests that a profound basis of subject matter knowledge is fundamental to effective teaching (Hill, Rowan, & Ball, 2005; Krauss et al., 2008). For instance, Borko and Putnam (1996) proposed that teachers should possess a rich and flexible knowledge structure of the subject domain in order to be able to effectively support students' learning. Empirical evidence supporting this claim can be found, for instance, in research on expert-novice communication. Hinds et al. (2001) conducted a study in the domain of electrical engineering in which they investigated how experts versus advanced students differed in their ability to generate instructional explanations on electric circuit tasks. They also investigated whether experts' versus advanced students' explanations differently affected novice students' near- and far-transfer of learning. Regarding the quality of the instructional explanations, Hinds et al. (2001) found that advanced students' explanations contained more concrete statements, whereas experts' explanations contained more abstract and advanced statements. More importantly, they demonstrated that advanced students' explanations were better suited to foster novice students' performance on near transfer tasks, whereas experts' explanations were more beneficial for enabling students to solve far-transfer tasks as compared to the explanations of advanced engineering students. Similar results were obtained by Boekhout, van Gog, van de Wiel, Gerards-Last, and Geraets (2010) in the domain of medicine. These researchers showed that worked examples, constructed by experts, led to benefits for novice students in transfer tasks as compared to advanced students' examples. However, there were no differences between experts' and advanced students' worked examples with regard to novices' performance on retention tasks. Together, both studies suggest that advanced students' explanations were less effective for enabling students to successfully transfer their knowledge to other tasks.

One possible reason that may explain the benefit of experts' explanations for students' transfer is the way experts differently organize their knowledge as compared to novice students or advanced, that is intermediate, students. Experts' and advanced students' knowledge structures fundamentally differ with regard to their coherence and knowledge encapsulation (Boshuizen & Schmidt, 1992; Chi, Feltovich, & Glaser, 1981). Coherence can be conceptualized as principled knowledge, which is characterized by the interrelatedness of domain-specific concepts and facts (Alexander, 2003; Gelman & Greeno, 1989). Compared to advanced students, experts tend to organize their knowledge around abstract principles which allow for the integration of superficially divergent concepts and subcomponents into a coherent, tightly connected schema (Chi et al., 1981). In contrast, advanced students rather organize their knowledge around superficial features which may not allow for the immediate integration of knowledge structures. Thus, advanced students possess more fragmented knowledge structures than experts. The second characteristic feature is knowledge encapsulation. On the way to becoming an expert, students transform their declarative knowledge into procedural knowledge (Ackerman, 1988). This proceduralized knowledge can be characterized by the subsumption of declarative detail knowledge under higher-level concepts (Boshuizen & Schmidt, 1992). In contrast, advanced students have not yet fully proceduralized their knowledge. Therefore, they rather operate upon detailed declarative knowledge. Thus, the encapsulation of experts' knowledge structures allows them to omit detailed knowledge while reasoning, whereas advanced students rather operate on a detailed declarative knowledge structure while reasoning.

3 Effective Instructional Explanations

The research reviewed so far concentrated upon differences regarding the effectiveness of experts' and advanced students' instructional explanations. Although Hinds et al. (2001) investigated expertise-related features of instructional explanations, they did not examine how and which of these features accounted for students' improved acquisition of flexible and transferable knowledge. For instance, according to Berthold and Renkl (2010), instructional explanations should be designed in a way that they trigger students' focused processing in order to help them to construct flexible and transferable knowledge. To engage students' focused processing, Kalyuga, Renkl, and Paas (2010) proposed that explanations of medium generality and high coherence should be adequate for students to develop flexible knowledge. Generality refers to the degree of details provided in an explanation. Explanations may have different levels of generality. For instance, the function of the human circulatory system can be explained (1) on a very general level as a blood distribution system, (2) at a medium general level as an organ system that supplies the body with nutrients, gases, and hormones, and (3) on an even more specific level, as an organ system consisting of the heart, blood, and blood vessels, including the pulmonary circulation, where blood is oxygenated, and the systemic circulation, providing the rest of the body with oxygenated blood which consists of plasma, red blood cells, white blood cells, and platelets.

Students often rely on superficial features of explanations while learning (Chi et al., 1981). Therefore, providing students with explanations of high specificity containing many details may result in a rather fragmented knowledge structure consisting of isolated components, so-called knowledge in pieces (diSessa, 1988). On the other hand, learning with very general and abstract explanations may not provide students with the necessary information that would allow them to develop a well-organized knowledge base. According to Kalyuga et al. (2010) explanations of medium generality can be regarded as an efficient compromise between explanatory power and intelligibility and may promote effective reasoning by students. For instance, Vidal-Abarca, Martínez, and Gilabert (2000) showed that explanations designed to trigger causal inferences in the reader by the omission of details improved students' learning outcomes.

The second feature of Kalyuga et al. (2010) is that explanations should be organized around principles that make interrelations between concepts explicit, which can be considered as coherence of explanations. One of the first experiments investigating coherence effects was conducted by Britton and Gülgöz (1991). The researchers increased the coherence of a textbook chapter by making important links between concepts more apparent. Thus, for instance they increased the overlap between arguments. Results showed that undergraduate students' performance in free recall and inference questions was better after reading the revised high-coherence text compared to reading the low-coherence text. Similar results showing the benefit of high-coherence text for students' learning could be found by McNamara and Kintsch (1996) and O'Reilly and McNamara (2007). However, as described in Sect. 2, student tutors might have problems in generating effective, highly coherent explanations that would enable students to construct flexible knowledge structures. Therefore, to analyze the quality of expert tutors' and student tutors' instructional explanations in detail, we developed a knowledge mapping approach.

4 Assessment of Tutor's Explanations with Knowledge Maps

As the results by Hinds et al. (2001) and Boekhout et al. (2010) indicated, student tutors in particular may face difficulties in generating explanations that are coherent and, at the same time, of medium generality. In order to assess the quality of instructional explanations, we developed a knowledge mapping approach that takes instructional explanations as input and constructs knowledge maps by segmenting instructional explanations into distinct propositions. A proposition is defined as a structure consisting of one relation and an ordered set of two concepts, containing the elementary idea units of the referring text base (Kintsch, 1988). To analyze an individual explanation, we construct a list of propositions which can then be visualized as a knowledge map (see Fig. 4.1). For the analysis of the generality and coherence

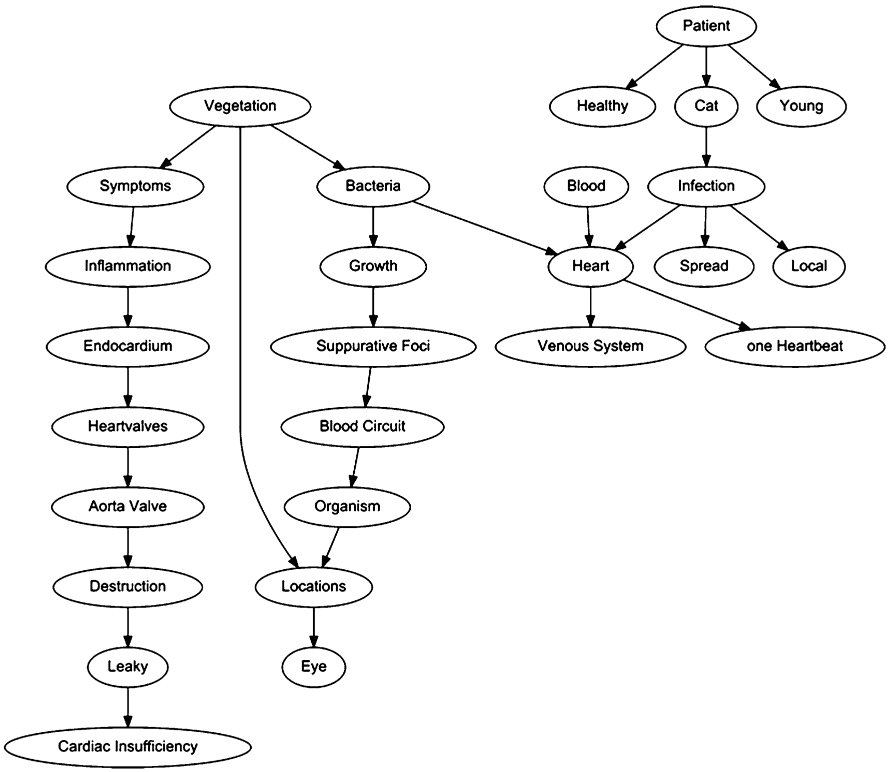

Fig. 4.1 Knowledge map derived from an expert's explanation about the reasons and processes of bacterial endocarditis

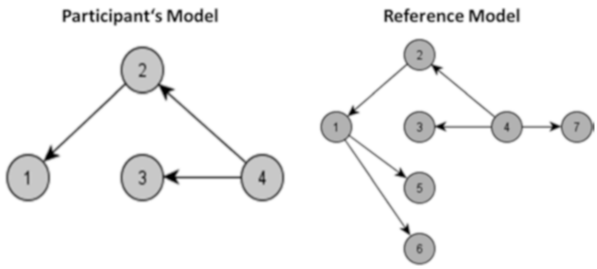

Fig. 4.2 Examples for a participant's model and a reference model (Lachner, Gurlitt, & Nückles, 2012)

of tutors' knowledge maps, we used indicators based on graph and set theory (Chein & Mugnier, 2009; Ifenthaler, Masduki, & Seel, 2011; Sowa & Shapiro, 2006).

4.1 Analysis of Explanatory Generality

Generality can be defined as the explanatory level of detail. For the generality of explanations we used two measures: omission of concepts and structural complexity.

4.1.1 Omission of Concepts

The *omission of concepts* is an indicator of how many details a tutor omits in his or her explanation. The more steps a tutor omits, the more general is the explanation. To identify the omissions, a reference model is needed (see Fig. 4.2).

This reference model must include all causal relations to sufficiently understand the phenomenon for which the explanation is written (e.g., ontologies of the subject domain could be used as reference models). Thus, the reference model depicts an "accurate" causal representation of the phenomenon. The omission of concepts is computed as the number of concepts that are in the set of the reference model (rm), but not in the tutors' model (pm), formally as: $\text{rm}\backslash\text{pm} = \{x \in \text{rm} \mid x \notin \text{pm}\}$.

When the reference model (Fig. 4.2) is compared with the tutors' knowledge map, concepts 5, 6, and 7 are present in the reference model but not in the knowledge map for the tutors in Fig. 4.2. In this case, we would have an omission of 3, because the tutor would have omitted three concepts in the instructional explanation.

4.1.2 Structural Complexity

The *structural complexity* is an indicator for how complex an explanation is and how many intermediate steps are necessary for navigating through the explanatory knowledge map. Thus, the higher the structural complexity is, the more intermediate steps are included that increase the level of detail and specificity. Mathematically, structural complexity describes the shortest path between the most distinct concepts of an explanation (Ifenthaler et al., 2011). It is computed as the shortest distance between the most distant nodes and can take values from 1 to *N*. A low value for structural complexity indicates high generality, whereas high *N* indicates a very detailed explanation, denoting low generality. Figure 4.2 shows an example for a fictitious knowledge map. In this example, the most distant nodes would be *Node 6* and *Node 7*, and the shortest path would include 4 edges; therefore, the structural complexity would be 4.

4.2 Coherence

Coherence can both be conceptualized on the level of the interrelatedness of concepts and on the level of cohesion of text segments (Ozuru, Briner, Best, & McNamara, 2010). Therefore, we developed two measures. On the local level of concepts, we analyzed the interrelatedness of concepts with each other. On the global level of text segments, we analyzed the fragmentation of the tutor's explanation (i.e., the cohesion of text segments).

4.2.1 Interrelatedness of Concepts

The interrelatedness of concepts can be computed by the proportion of the sum of edges *e* and the sum of nodes *v*, formally as:

$$\frac{\sum_{i=1}^{n} e_i}{\sum_{i=1}^{n} v_i}$$

This expression describes the average relatedness of concept to concept and can take values between 0 and 1, where 0 represents a nonconnected graph and 1 means that all concepts are directly related to each other. Figure 4.3 shows an example of a knowledge map consisting of six relations and nine concepts. The interrelatedness of concepts for the example graph would be $6/9 \approx 0.67$.

4.2.2 Fragmentation

On the propositional level of explanatory coherence, we computed the *fragmentation* of the explanation. Fragmentation can be considered as an indicator for the

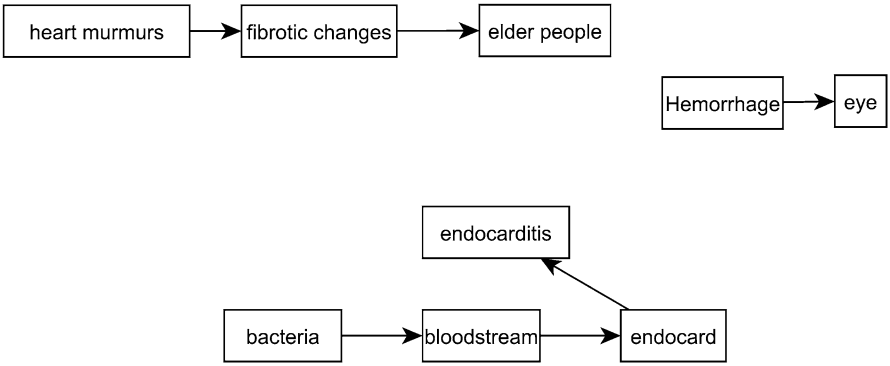

Fig. 4.3 Fragmentation in an explanatory knowledge map (Lachner et al., 2012)

ruggedness of an explanation. In contrast to interrelatedness of concepts, fragmentation measures the number of unconnected knowledge units of the instructional explanations. Mathematically, a knowledge unit is represented as a disconnected component in a knowledge map, indicating a submap that is not connected to the rest of the knowledge map. Formally, we define fragmentation as the number of components C_n which are subsets of the graph G, where each node $v \in V$ has no edge connection to the set of nodes v of the complement of $G \backslash C_n$ (Sowa & Shapiro, 2006). The knowledge map depicted in Fig. 4.3 would have a fragmentation index of 3, because there are three disconnected subcomponents in the knowledge map.

5 Empirical Findings for the Effectiveness of Knowledge Maps for Assessing Tutors' Explanations

In this section we present three studies that we had conducted with our knowledge mapping approach. The first study examined how expert tutors' and student tutors' explanations differed regarding the features of coherence and generality. Therefore, we used our knowledge mapping approach with measures for generality and coherence. Additionally, we present two follow-up studies that demonstrated the predictive validity of our knowledge mapping approach. First, we investigated how student tutors' and expert tutors' explanations affected students' transfer and more importantly, if our knowledge mapping measures were able to predict students' transfer of knowledge. Second, we present findings regarding the question as to whether these features can also predict students' processing. Thus, we examined how these expertise-related features—analyzed with our knowledge mapping measures—affected students' processing of the explanations. The aim of this section is to highlight relevant results concerning the validity of our knowledge mapping approach.

5.1 Using Knowledge Maps for Investigating Expertise-Related Features of Explanations

In the first study (see Lachner et al., 2012), we addressed the question of whether our knowledge mapping measures for generality and coherence would be able to detect differences between expert tutors and student tutors with regard to the generation of instructional explanations. As expert tutors are supposed to have encapsulated and highly coherent knowledge structures (Boshuizen & Schmidt, 1992; Chi et al., 1981), they were expected to generate more general explanations as compared to student tutors' explanations. Specifically, expert tutors were supposed to present structurally less complex explanations (indicated by fewer intermediate steps) and omit more concepts in their explanations. At the same time, experts should generate more coherent explanations as compared to student tutors. Thus, expert tutors' explanations should be more interrelated and less fragmented.

5.1.1 Participants and Research Design

Expert tutors were recruited from a cardiology hospital in Germany. They had around 19 years of working experience and assessed their teaching experience as very high. Student tutors were recruited from medical programs and were in their fifth year of their studies. In order to assess the generality and coherence of student tutors' and expert tutors' explanations, we used a quasi-experimental between subjects design with tutors' expertise as the independent variable. Dependent variables encompassed the generality and coherence of their explanations. In total six expert tutors and six student tutors were participated in the study.

5.1.2 Materials and Procedure

We provided student tutors and expert tutors with a clinical case description of bacterial endocarditis, an inflammation of the heart valves that included both context information and laboratory findings. The case description was taken from studies by Patel and Groen (1986). The entire study lasted approximately 35 min. First, tutors completed the demographic questionnaire (5 min). Second, they read the case description (5 min). Third, tutors had to provide an instructional explanation for the case description in complete sentences (25 min). For the analysis of the explanations regarding generality and coherence, we used our knowledge mapping measures. Thus, we segmented the instructional explanations into propositions and visualized the propositions as a knowledge map. Subsequently, we computed our four measures for generality and coherence for each participant.

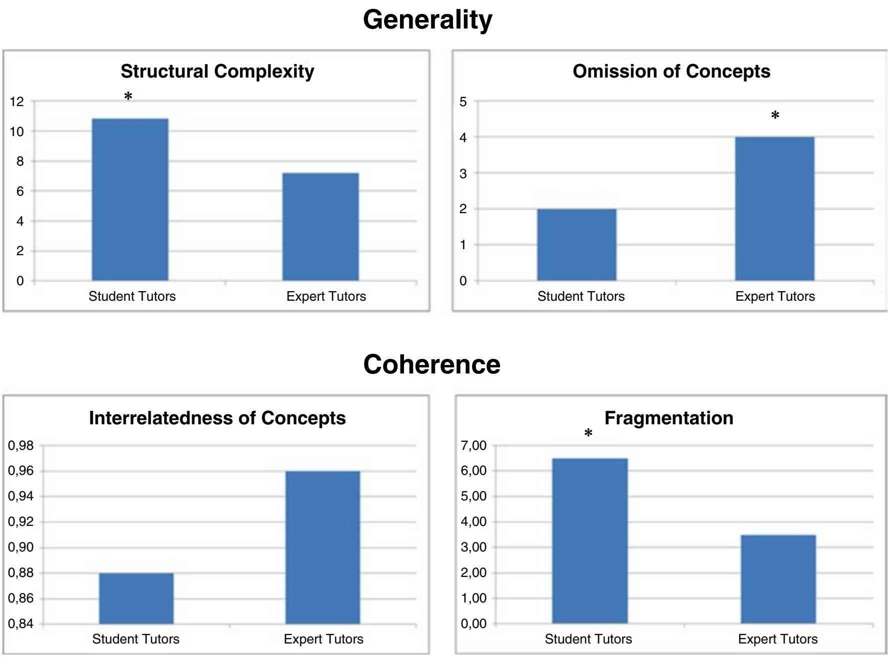

Fig. 4.4 Mean scores of coherence and generality for student tutors and expert tutors. Differences with $*p<0.05$ are marked by an *asterisk*

5.1.3 Summary of Results

To compute differences between expert tutors and student tutors, we computed one-way ANOVAs with type of explanation (expert tutor or student tutor) as independent variable and the measures of generality and coherence as dependent variables. For the generality of tutors' explanations we could show that expert tutors' explanations were more general compared to student tutors' explanations. Expert tutors omitted more concepts in their explanations and had less complex explanations (i.e., fewer intermediate steps) as compared to student tutors' explanations (see Fig. 4.4).

With regard to the fragmentation of the explanations, student tutors' explanations were significantly more fragmented than experts' explanations (see Fig. 4.4). Although descriptive data for the interrelatedness of concepts showed a tendency that expert tutors' explanations were more interrelated than student tutors' explanations, we did not find any significant differences for the interrelatedness. Apparently, student tutors' explanations were as interrelated as expert tutors' explanations.

In sum, expert tutors omitted more concepts in their explanations, which resulted in less complex explanations. Because they provided fewer details, expert tutors' explanations were more general compared to student tutors' explanations. At the same time, expert tutors' explanations were more coherent, meaning that they tried to integrate different knowledge units into a tightly coherent and thus less fragmented explanation.

5.2 *Predictive Validity of Knowledge Mapping Measures for Students' Learning*

In our first follow-up study, we addressed the question of whether our knowledge mapping approach can trace beneficial features of expert tutors' and student tutors' explanations for students' learning (more specifically for students' conceptual knowledge gain and students' transfer of learning), which would be a sign for the predictive validity of our knowledge mapping measures. For students' transfer of learning, we assumed that expert tutors' explanations would be more appropriate compared to student tutors' explanations. For students' conceptual knowledge gain, we refrained from making clear predictions, as research by Hinds et al. (2001) and Boekhout et al. (2010) showed mixed evidence for analogical tasks (e.g., near transfer tasks, retention tasks but also conceptual knowledge tests). More importantly, as proposed by Kalyuga et al. (2010), we investigated if medium generality and high coherence of instructional explanations can be considered as the mediating variables between type of explanation (expert tutor or student tutor) and students' transfer of learning.

5.2.1 Participants and Research Design

Ninety-eight medical and biology students from the University of Freiburg in Germany participated in the study. They were on average in their second semester and none of them had taken courses in cardiology yet. Participants were randomly assigned to one of the twelve explanations generated by expert tutors or student tutors. We used a pretest–posttest design with the instructional explanations nested within the factor type of explanations—that is, expert tutors' explanations or student tutors' explanations. Dependent variables encompassed the participants' acquisition of conceptual knowledge, specifically their understanding of central concepts of bacterial endocarditis and their relations, as well as students' ability to transfer their biomedical knowledge acquired from the explanations to other medical phenomena, measured by a transfer test.

5.2.2 Materials and Procedures

We provided the participants with the general case description already used in Study 1 (see Sect. 5.1). Additionally, they received one of the twelve explanations written by a student tutor or an expert tutor.

A conceptual knowledge test was used as pre- and posttest to measure students' conceptual knowledge about bacterial endocarditis. The test consisted of nine multiple choice items which measured students' understanding of the processes of bacterial endocarditis (such as "what is a possible therapy for bacterial endocarditis?"). For the conceptual knowledge test, a total of nine points could be obtained.

Additionally, a transfer test measured students' ability to apply their acquired knowledge about bacterial endocarditis to other medical phenomena. Questions in the transfer test were open ended and asked, for instance, "Why can an endocarditis result in a cardiogenic shock?" or "Can an endocarditis be the cause for a stroke?" In the transfer test students could receive nine points at maximum. The open-ended questions of the transfer test were scored by a rater who was blind to the treatment condition according to reference answers generated by a medical expert. The whole experiment lasted about 60 min. In the pretest phase, participants first answered the conceptual knowledge test (10 min) that assessed their prior knowledge about concepts and facts concerning bacterial endocarditis. Then, in the learning phase, they received the case description and one of the randomly assigned explanations produced by a student tutor or an expert tutor (25 min). In the posttest phase participants answered the conceptual knowledge test again (10 min) and they answered the transfer test (15 min).

5.2.3 Summary of Results

We conducted ANCOVAS with type of explanation (student tutor's explanation, expert tutor's explanation) as independent variable; students' learning (conceptual knowledge, transfer) as dependent variables and students' prior knowledge as covariate. For students' conceptual knowledge gain, we did not find any significant differences between student tutors' explanation and expert tutors' explanations. Therefore, explanations by student tutors were as good as expert tutors' explanations for gaining a conceptual understanding about bacterial endocarditis. For our transfer hypothesis, we similarly conducted an ANCOVA with type of explanation as independent variable, students' transfer as dependent variable and prior knowledge as covariate. In line with our transfer hypothesis, we found that students with expert tutors' explanations significantly outperformed students with student tutors' explanations. Therefore, expert tutors' explanations were more appropriate to gain flexible knowledge compared to student tutors' explanations. To account for which features were most beneficial for students' transfer of knowledge, we computed contrast analyses (Rosenthal & Rosnow, 1985) with "explanations" as the independent variable and the students' transfer scores as the dependent variable. As we expected a linear relationship between coherence and students' transfer, we computed a linear contrast for fragmentation with contrast weights based on the raw fragmentation scores of each explanation. Contrast analyses revealed that the linear relationship between fragmentation and students' transfer was highly significant ($p < 0.001$), indicating that less fragments were more beneficial for students' transfer of knowledge. Similarly, we computed quadratic contrasts for our generality measures (omission of concepts and inference path), indicating that medium generality accounts best for students' transfer. However, the contrast was neither significant for the omission of concepts nor for the structural complexity, indicating that generality did not account for students' transfer. Therefore, we can conclude that fragmentation as a coherence indicator accounted best for students' transfer. Additional mediation analyses showed that it was especially fragmentation which mediated the effect of expert tutors' explanations on students' transfer of learning. Thus, expert tutors made less fragmented explanations, which most accounted for the benefit of students solving transfer tasks. Results of this study indicate that our knowledge mapping approach is capable of eliciting relevant features of instructional explanations that account for students' ability to flexibly transfer their knowledge to other phenomena. Therefore, we can conclude that high coherence of instructional explanations is especially important for gaining flexible knowledge structures.

5.3 Predictive Validity of Knowledge Mapping Measures for Students' Processing

As the fragmentation of explanations could predict students' transfer, we investigated how fragmentation affected students' processing of the explanations (for more details see Lachner & Nückles, 2013). Therefore, we conducted a thinking aloud study. In line with Berthold and Renkl (2010), we examined if high coherence (i.e., low fragmentation) triggered students' focused and deep processing, whereas low coherence (i.e., high fragmentation) rather affected students' shallow processing. Therefore, we selected the two expert tutors' explanations with the lowest fragmentation index (expert tutor A had 1 fragment and expert tutor B had 3 fragments in the explanation) and the two student tutors' explanations with the highest fragmentation index (both student tutors had 8 fragments in their explanations).

5.3.1 Participants and Research Design

Sixty-eight medical and biology students from the University of Freiburg (Germany) participated in the study. They were on average in their first semester and none of them had taken courses in cardiology yet. Participants were randomly assigned to one of the four explanations generated by expert tutors or student tutors. We used a pretest–posttest design with type of explanations, i.e., expert tutors' explanations or student tutors' explanations, as independent variable. Dependent variables included the participants' acquisition of conceptual knowledge as well as students' ability to transfer their biomedical knowledge acquired from the explanations to other medical phenomena, measured by the transfer test. Additionally, we collected students' processing activities (paraphrasing and self-explanations).

5.3.2 Materials and Procedures

We provided the participants with the same materials as in Study 2, the case description, one of four explanations, the conceptual knowledge test as pre- and posttest and the transfer test. The whole experiment lasted about 60 min and was identical

Table 4.1 Categories for the categorization of the thinking aloud protocol (Lachner & Nückles, 2013)

Category	Description	Examples
Paraphrase	Student simply restated or paraphrased a text segment from the explanation	The explanation says that fever can have different causes
Self-explanations	Student connected new information with prior knowledge by self-explaining	Splen is Latin for spleen and megaly is an enlargement, therefore splenomegaly is an enlargement of the melt

with the last experiment, except for the fact that students had to think aloud while learning. For the analyses of students' processing activities, their thinking aloud protocols were transcribed and segmented into idea units (Chi, 1997). Based on Chi (2000), each idea unit was categorized as one of the following learning activities (see Table 4.1). Interrater reliability was very good.

5.3.3 Summary of Results

To investigate whether the results of Study 2 concerning students' learning gain can be replicated, we computed ANCOVAS with type of explanation as independent variable, students' knowledge gain as dependent variable and students' prior knowledge as covariate. Similar to the findings of the last experiment, we did not find any significant differences concerning the conceptual knowledge gain between students learning with an expert tutor's explanation and a student tutor's explanation. In line with the last study, for students' transfer we found that students who studied with an expert tutor's explanation outperformed students learning with a student tutor's explanations. To investigate how these explanations eventually differ, we analyzed students' processing activities of the explanations. Figure 4.5 shows the mean proportions of the processing activities for the different fragmentation scores. Similar to analyses in Study 2, we computed contrast analyses (Rosenthal & Rosnow, 1985) with "explanations" as the independent variable and students' processing as dependent variable. For testing our linear trend hypothesis that higher fragmentation lead to more paraphrasing and less self-explanations, we computed a linear contrast with contrast weights based on the raw fragmentation scores of each explanation. As the results indicated, the test of the linear contrast proved to be significant, both for paraphrasing, indicating that high fragmentation mainly accounted for students' shallow processing (i.e., paraphrasing), whereas low fragmentation, which is high coherence, led to students' deep processing of the explanation (i.e., self-explanations).

5.4 Discussion

The findings of our three studies suggest that our knowledge mapping measures are capable of detecting expertise-related features that are relevant for students' learning.

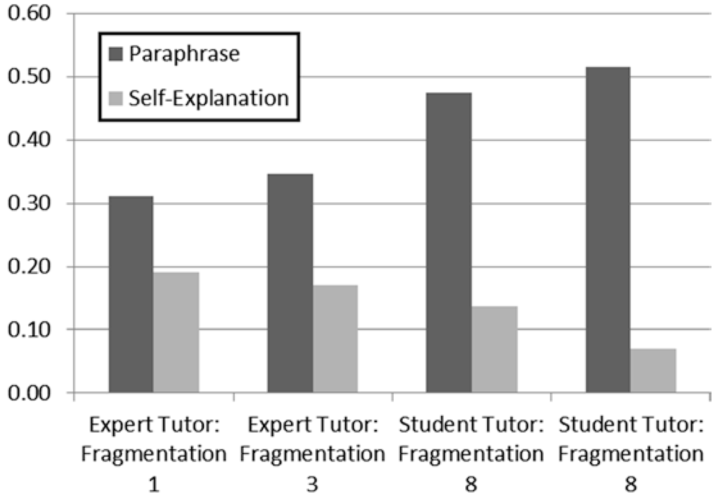

Fig. 4.5 Mean proportions of paraphrasing and self-explanations for the explanations based on their fragmentation score

In the first study, we could show that our knowledge mapping measures are capable of detecting expertise-related features of instructional explanations such as coherence and generality. We could show that expert tutors wrote more *general* explanations measured by the omission of concepts and the structural complexity as compared to student tutors. In a similar vein, expert tutors also generated more *coherent* explanations, as indicated by the fragmentation index. Thus, we can conclude that our measures are well suited to analyze expertise-related features of explanations. In two follow-up studies, we showed that the reported knowledge mapping measures enabled us to predict students' learning outcomes and students' processing of explanations. These results demonstrate the predictive validity of our knowledge mapping measures. In Study 2, we could replicate that expert tutors' explanations were better suited to support students' flexible transfer of knowledge. More importantly, we showed that the benefit of expert tutors' explanations was mediated by the fragmentation of the instructional explanation. This means that experts generated less fragmented explanations, which in turn better supported students' transfer. In line with this result, in our third study we showed that the degree of fragmentation of an explanation dramatically influenced the way students processed the explanation. Students learning from expert explanations with a very low degree of fragmentation followed a deep approach of processing: they produced more self-explanations as compared with students learning with the more fragmented explanations of advanced students. In contrast, the higher degree of fragmentation of student tutors' explanations rather triggered novice students to paraphrase the explanation. This can be understood as shallow processing. Thus, we can conclude that the high coherence of instructional explanation is an important prerequisite for the construction of flexible knowledge. However, as Study 2 and Study 3 imply, student tutors may face problems to write coherent explanations and may need support in writing coherent instructional explanations.

6 Knowledge Maps as Support for Writing Explanations

As our methodology proved to be effective for detecting crucial explanatory features for students' learning, we developed a first prototype of a self-awareness tool for supporting tutors in generating coherent explanations. The basic methodology for the self-awareness tool was our knowledge mapping approach. The knowledge maps constructed from an explanation could, in particular, help tutors revise their explanation. Tutors may initiate a revision of their explanations by detecting problems in an existing explanation (Hayes, 2012). However, due to the fragmented knowledge structures of student tutors, they might not be aware that fragmentation of a text may face problems for potential readers. By visualizing their explanations, the fragmented nature of their explanations could be made explicit and thereby induce a reactivity effect. Therefore, student tutors would be more likely to revise their explanation in order to increase the coherence of their explanation (Cho, Cho, & Hacker, 2010). To induce such a reactivity effect, we implemented a first prototype of the self-awareness tool and completely automated our knowledge mapping approach (both the propositional segmentation and coherence indicators) to support tutors' deliberate self-monitoring and metacognitive awareness in order to enhance the coherence of their instructional explanations. Figure 4.6 shows the different technical modules of our knowledge mapping prototype. It consists of a preprocessing module and a feedback module.

The preprocessing module takes the instructional explanation as input and segments the instructional explanation into a propositional list. First, the RF-tagger, a

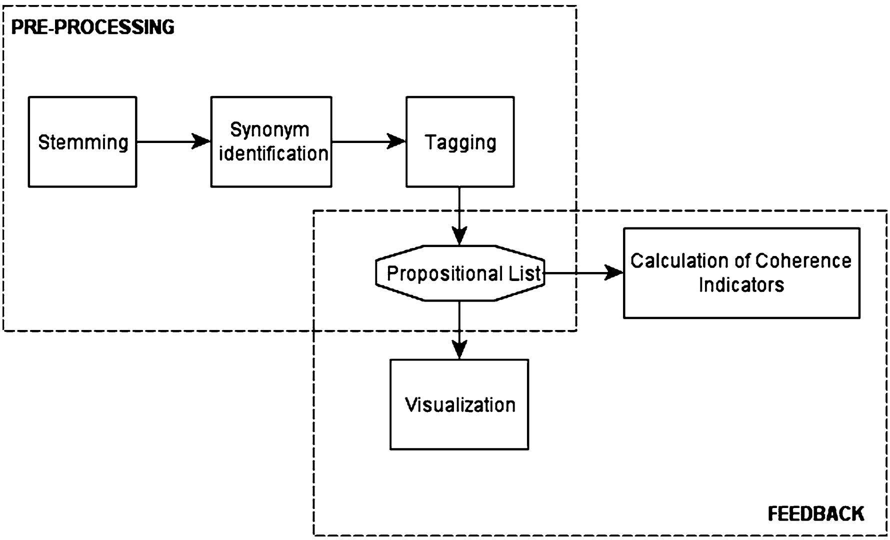

Fig. 4.6 Modules of the knowledge mapping tool

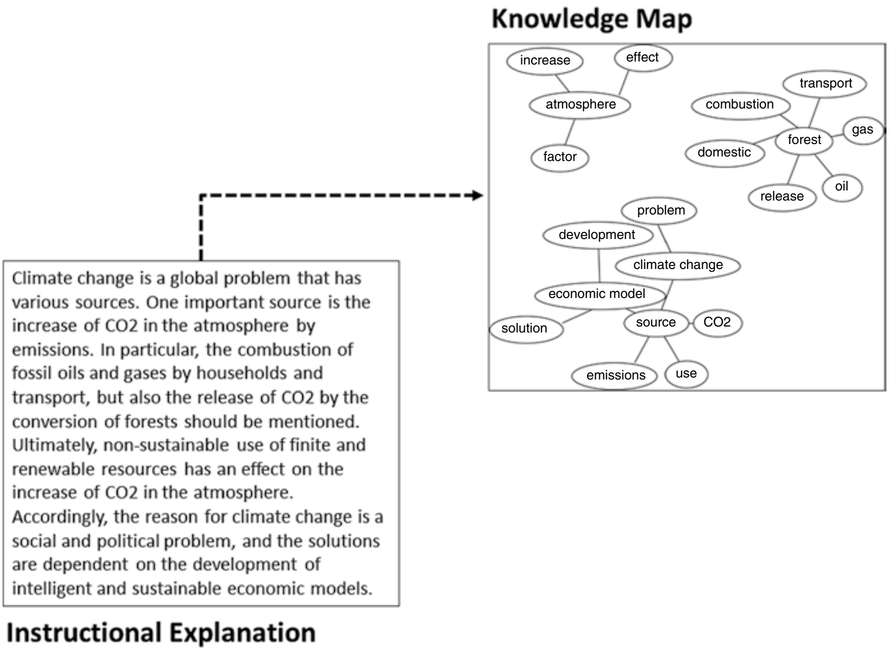

Fig. 4.7 Example for the automated visualization of an instructional explanation about global warming

special kind of part-of-speech-tagger (Schmid & Laws, 2008) decomposes the instructional explanations into sentences and determines the syntactical function of each word. Second, inflected or derived words are reduced to their stems, which are their root forms, by the Porter algorithm (Porter, 1980). Thus, words with the same source can be more easily detected (such as cats—cat). Subsequently, the nouns are selected and the propositions are built by using the following heuristic: to build up a propositional list, the relations between the concepts are drawn according to their grammatical function: subject antecedes objects. Indirect objects antecede direct objects. For instance, the sentence *Bob's son gives Clara a bike* would be represented as: Son → Bob; Son → Clara; Son → Bike; Clara → Bike. With this heuristic we derive a propositional list, which is the basis for the feedback module. Tutors both receive graphical feedback as well as numerical feedback. For graphical feedback, the propositional list is visualized with the visualizing tool GraphViz (Ellson, Gansner, Koutsofios, North, & Woodhull, 2003) as a knowledge map. An example for the visualization can be seen in Figure 4.7. For numerical feedback, tutors additionally receive the results of the coherence measures (fragmentation and connectedness) as a component of feedback.

7 General Discussion and Future Directions

Explanations are a prevalent strategy in instruction. However, often student tutors' explanations are not very effective for students' transfer of knowledge. Based on this background, we developed a knowledge mapping approach for investigating expertise-related features of instructional explanations and their effect on students' processing and learning outcomes. Our knowledge mapping approach takes an instructional explanation as input and automatically computes different measures for coherence and generality based on graph theory. With this approach we could show that due to experts' encapsulated and coherent knowledge structures, expert tutors omitted more details in their explanation compared to student tutors. Likewise, they wrote less fragmented (i.e., more coherent) explanations. Investigating the predictive validity of our knowledge mapping approach, we investigated whether these measures are capable of tracking relevant explanatory features that have an impact on students' learning. The main finding was that the fragmentation of the instructional explanation had a significant impact on students' learning. Fragmentation mainly triggered students' shallow processing, meaning that they simply paraphrased the explanation, whereas less fragmented explanations mainly induced students' deep processing by evoking self-explanations. In line with this reasoning, the deep processing of the explanation mainly caused students to construct more elaborated and flexible schemata, which allowed them to transfer their knowledge to other tasks more effectively. These results encouraged us to further develop our knowledge mapping approach as a self-awareness tool for supporting student tutors writing coherent instructional explanations. Therefore, we completely automated the visualization procedure to immediately provide feedback for student tutors' writing explanations. However, the effectiveness of our knowledge mapping approach as a self-awareness tool has not been examined yet. Therefore, future studies should examine whether our knowledge mapping approach could induce a reactivity effect, or more specifically, if feedback by a knowledge map may facilitate student tutors' metacognitive awareness of fragmentation in their explanations in order to improve their instructional explanations. Additionally, it should be investigated if explanations generated with the help of the self-awareness tool would be better suited to engage students' learning compared with explanations generated without the self-awareness tool.

Our findings are consistent with prior research. First, we could replicate that student tutors' explanations are less capable of supporting students' transfer of learning (Boekhout et al., 2010; Hinds et al., 2001). Second, our studies extend previous findings in the following way: we showed that expert tutors' coherent instructional explanations triggered deep and integrated comprehension processes in students which aimed at the construction of flexible knowledge. In contrast, student tutors' fragmented explanations rather prompted students to shallowly process the explanation (Chi et al., 1981; diSessa, 1988). Thus, expert tutors' coherent explanations can be regarded as a powerful means for students to actively monitor, regulate and control their processing activities, which is in line with findings from text comprehension research (McNamara & Kintsch, 1996; O'Reilly & McNamara, 2007) and also with research on self-regulated learning (Paris & Paris, 2001; Schraw, 1998; Zimmerman, 2002).

As proposed by Kalyuga et al. (2010), we could show that the fragmentation of instructional explanations mainly accounted for students' focused processing and flexible construction of knowledge. However, the generality (or level of specificity) of an explanation did not affect students' learning. Nevertheless, generality and coherence are not mutually exclusive. Providing information of medium generality has an impact on the explanatory coherence, because relevant and important relations between concepts are not covered by seductive details (diSessa, 1988). Thus, the coherence of the explanations could be increased as well, which serves students as a meaningful domain schema for acquiring deep and interrelated knowledge.

Based on these findings, we proposed a knowledge mapping approach in order to support student tutors in giving coherent explanations. So far, tutors' revision of instructional explanation is supported. Additionally, the planning phase has to be supported as well. Thus, our knowledge mapping approach could be extended by a diagnostic component to generate more student-tailored explanations that directly address students' needs (Wittwer et al., 2010). By taking the prior knowledge of the prospective audience, namely the students, into account, student tutors could additionally be supported in their planning of writing and in the writing process itself, because student tutors would be more capable of taking prior knowledge of students into account with the help of the diagnostic component (Hayes, 2012; Wittwer et al., 2010). Thus, instructors with little teaching experience could be supported in successfully providing students with tailored and coherent explanations.

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Chapter 5
Investigating Through Concept Mapping Pre-service Teachers' Thinking Progression About "e-Learning" and Its Integration into Teaching

Wan Ng

Abstract The chapter reports on a study that aimed to investigate the thinking progression and understanding of second year undergraduate pre-service teachers about the concept of "e-learning" before and after the completion of the course *Introduction of e-learning*. It sought to understand what the students selected as keywords that were associated with e-learning for their pre-course concept maps and how they shifted them in the post-course concept maps to demonstrate their understanding of e-learning and in particular its integration into teaching and learning. A framework for e-learning in the context of teacher education and pre-service teachers' preparation for ICT integration into professional teaching is developed that forms the basis for the qualitative analysis of the concept maps. The study takes a case-study approach where growth (or non-growth) in thinking between pre- and post-course concept maps was studied in more detail for nine cases, three in each of the high-, middle- and low-scoring groups. The chapter presents and discusses the variations in the students' thinking as demonstrated by their concept maps, and discusses the benefits and limitations of using concept maps in capturing pre-service teachers' understanding of e-learning and its integration into their professional teaching.

Keywords Undergraduate pre-service teachers • Pre- and post-concept maps • Conceptual understanding • e-Learning and integration into teaching and learning

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1 Introduction

Concept maps were developed in psychology to understand mental representations of topic knowledge and thinking processes. Developed by Novak and Gowin (1984), they are visualisation tools that can be used to capture learners' conceptual change over time. The visual representations of key concepts or ideas linked together by single words or short phrases to show their inter-relationships demonstrate how the learner connects concepts within the topic to reveal the specific changes in knowledge construction over time. In this respect concept mapping should be a part of a teacher's repertoire of assessment methods. It is especially useful as a formative assessment tool where missing or incorrectly placed conceptual keywords could be easily recognised and acted upon accordingly in the teacher's follow-up design of his/her instructions. The aim of this chapter is to report on a study on the use of concept maps to capture undergraduate pre-service teachers' understanding of e-learning and its integration into teaching in the unit *Introduction of E-learning and Technology-enabled Teaching.* The research questions were:

1. How do second year undergraduate pre-service students make use of concept maps to create representations of understanding of e-learning and its integration into teaching/learning?
2. How does the conceptual understanding of e-learning change, as demonstrated in their post-course concept maps, upon completion of the e-learning course for the semester?
3. What kinds of patterns emerge in the case studies' concept maps of high-, medium- and low-scoring students?

This chapter first establishes why understanding about e-learning and how it is applied to teaching is an important component of teacher education. Then it defines e-learning and constructs a theoretical framework for the study. This is followed by a discussion of the use of concept maps to capture this understanding in pre- and post-course concept maps and presents the qualitative analysis for the study of nine case studies, three from each of the categories of high-, medium- and low-scoring students' achievements. The analysis and discussion of the data are informed by the theoretical framework developed for the study. Finally, the limitations of the study and the implications of using concept maps in teacher education are discussed.

2 e-Learning in Teacher Education

2.1 e-Learning

e-Learning is frequently defined in the literature to mean online or virtual learning. For example, Jones (2003) and Wan, Wang, and Haggerty (2008) defined e-learning as occurring in virtual learning environments in which the learners' interactions with resource materials, instructors and/or peers are mediated through Information and Communication Technologies (ICTs) so that learning can occur anytime and anywhere. Broader definitions are provided in the literature to mean just the use of telecommunication technology to deliver information for education and training (Sun, Tsai, Finger, Chen, & Yeh, 2008), while Wright (2010) citing the New Zealand Ministry of Education (2002, p. 5) stated that e-learning is

> …flexible learning using ICT resources, tools, and applications, and focusing on interactions among teachers, learners, and the online environment. e-Learning usually refers to structured and managed learning experiences, and may involve the use of the Internet, CD-roms, software, other media, and telecommunications.

Within the context of this study, the broader definitions are embraced. It defines e-learning as learning that is facilitated by the use of digital tools and would typically involve some form of interactivity. The interactions include

- *Online interactions* between the learner and their teachers and/or peers that are Internet based, e.g., emailing and collaborating using Web 2.0 technologies such as blogging and creating wikis.
- *Offline interactions* between the learner and digital resources, e.g., with word processor, spreadsheet, simulations and drill and practice, audio and visual editing programs.

2.2 The Need for Understanding About e-Learning in Teacher Education

The reasons for why it is crucial for pre-service teachers to understand about e-learning are:

1. Considering the changes in our society where computers are present in almost all homes and the workplace, e-learning is a fact of life for students at school and at home. e-Learning is necessary to support (rather than replace) traditional schooling and lifelong learning (Anderson, 2005; Jones, 2003). Increasingly, students are gaining more knowledge informally and being more connected to online (global) communities through technology. Schools need to acknowledge this practice and embrace students' informal learning and development of technology skills in the classroom.
2. e-Learning exploits both offline and web-based technologies and offers new ways to collaborate and build learning communities to improve students' learning outcomes.
3. e-Learning shifts learning environments from teacher-centred approaches to student-centredness where the students take greater responsibility for their own learning.

2.3 Framework for Demonstrating Understanding of e-Learning and Its Effective Integration into Teaching and Learning

In order to evaluate pre-service teachers' growth in their understanding of the topic of e-learning and its effective integration into teaching and learning, the study is guided by a framework that depicts the main dimensions that the pre-service teachers need to demonstrate understanding in. These dimensions are:

1. Skills and knowledge of available educational technologies and their affordances: being digitally literate
2. Understanding of the characteristics and practices of the students the pre-service teachers will teach and how the students learn in technologically enhanced environments
3. Knowledge of the pedagogy of teaching content in their specialist area and embracing ICT to facilitate their teaching and students' learning.

2.3.1 Skills and Knowledge of Available Educational Technologies and Their Affordances: Being Digitally Literate

The incorporation of new technologies into teaching is an essential component of a teacher's repertoire of classroom practices. There are, however, literally hundreds of educational technology tools (both online and offline) that are available for teaching and learning in the classroom (see, e.g., *Cool Tools for Schools,*[1] *Online Tools and Applications*[2] and *Top 100 Tools for Learning*[3] websites). Pre-service teachers need to have skills and knowledge of the available educational tools and their affordances, that is, the features, functions and capabilities of these tools. They need to possess sufficient levels of digital literacy to make use of these tools for educational purposes. According to Ng (2012), digital literacy has three dimensions: (1) technical, (2) cognitive and (3) social-emotional. The technical dimension of being digitally literate broadly means possessing the technical and operational skills to use ICT for everyday activities and in manoeuvring the capacity of specific software for the purpose of enhancing teaching and learning performance. The cognitive dimension of digital literacy is associated with the ability to think critically in the search-evaluate-create cycles of handling digital information. It means being innovative with technology, that is, being able to assess, select and re-purpose appropriate software programs for educational purposes. It also means being knowledgeable about ethical, moral and legal issues associated with both online and offline digital technologies as well as the understanding of multiliteracies (New London Group, 1996)

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[1] http://cooltoolsforschools.wikispaces.com/

[2] http://www.go2web20.net/

[3] http://www.slideshare.net/janehart/top-100-tools-for-learning-2011

that involves the ability to decode information that are text-based and information from images, sound bytes (e.g., podcasts), videos, maps and models. This ability to decode different representations of information involve multiliteracies skills that are linguistic, visual, audio, spatial, gestural (as captured in videos) and multimodal (as in multimedia resources). The social-emotional dimension of digital literacy means adopting the right attitudes toward, and being able to use the Internet responsibly for communicating, socialising and learning as well as being able to protect oneself from adversity associated with online presence such as cyberbullying or (personal) information theft. These dimensions of digital literacy should be developed in pre-service teachers.

2.3.2 Understanding of the Characteristics and Practices of the Students the Pre-service Teachers Will Teach and How the Students Learn in Technologically Enhanced Environments

Students born in and after 1980 have been called digital natives (Prensky, 2001), millennials and the net-generation (McMahon & Pospisil, 2005; Oblinger, 2003; Oblinger & Oblinger, 2005). These students are characterised as digitally literate people who are frequent online users and who embrace technology in their everyday lives, using it as a central plank for their relationship building. They are networked socially through technology and stay in contact with friends, family and peers via email, mobile phones, Short Message Service (SMS), Skype, Social Networking Sites (SNS), discussion boards and chat rooms. They become part of online communities and collaborate to create and share information on the Web using Web 2.0 technologies. Nixon, Atkinson, and Beavis (2006) have argued that students' activities outside schools embrace ICT in this manner where they are engaged in communicative networks that are not only for recreational purposes but also for the exchange of skills and knowledge. Through mobile devices, this network of a "multiplicity of communicative relationships" (p. 133) is enhanced, both formally and informally.

Even though these students have grown up with technology, existing learning theories that support learning with technology still apply. This is in accordance with Nichols (2003, p. 6) e-learning principle that the essential process of education, that is, enabling the learner to achieve planned learning outcomes, does not change when e-learning is applied. These learning theories include social-constructivism (Bruner, 1966; Piaget, 1972; Vygotsky, 1978), multiple intelligences (Gardner, 1999) and constructionism (Papert, 1980). Social-constructivism is a highly popular learning theory that supports learning with and without digital technologies. It has two components—cognitive and social. The cognitive aspect of constructivism conceives that the acquisition of knowledge requires the learner to be actively engaged in the learning process, at the operational level where the learner is engaged in physical manipulations (e.g., technically creating a wiki) and at the cognitive level where he/she is mentally processing incoming information and stimuli (e.g., listening to a podcast or visualising and listening to a multimedia presentation). In addition to this cognitive aspect of constructivism, Vygotsky (1978) proposed that social interactions between the learner and the teacher/peers promote better construction of knowledge. In an e-learning environment that is based on social-constructivism, the role of the teacher is to scaffold the learning by using appropriate technology to teach or demonstrate concepts (e.g., through simulations) or engage the students in creating artefacts to demonstrate what they have learnt.

Blended into constructivist learning theory is the theory of constructionism (Papert, 1980). According to Papert, students are more motivated and engaged in their learning when they are constructing a public artefact that others will see, critique and use. There are many cost-free tools that are Web 2.0 technologies that enable the creation of knowledge artefacts (e.g., ePortfolios, wikis, blogs, glogs, popplets) and there are avenues online to display them to a wide audience, for example through YouTube.

A learning theory that considers learning styles is Gardner's (1999) multiple intelligences theory which posits that there are nine intelligences that people possess, often in combination. These are bodily-kinaesthetic, logical-mathematical, linguistic, visual-spatial, musical, interpersonal, intrapersonal, naturalistic and existential intelligences. The theory caters for the diversity of students with preferences for different modes of learning which could be addressed through the multimodal capacity of ICT in representing meanings, e.g., through visual, audio, verbal (text and audio), musical and gestural (captured in video recordings) modes.

In demonstrating understanding of e-learning and its integration into teaching and learning, pre-service teachers should be able to apply these and other learning theories appropriate for learning with ICT, for example, situated learning (e.g., use of mobile technologies), computer supported collaborative learning (e.g., collaborative project work using online tools such as GoogleDocs or WikiSpaces) and inquiry-based learning (e.g., WebQuest).

2.3.3 Knowledge of the Pedagogy of Teaching Content in Their Specialist Area and Embracing ICT to Facilitate and Support the Pedagogy

Pedagogical Content Knowledge (PCK) is defined as the combination of content and pedagogy that is a teacher's unique form of professional understanding (Shulman, 1986, 1987). The interrelationship between content knowledge and pedagogy requires pre-service teachers to learn different ways of representing subject matter. Embracing ICT to facilitate teaching and learning is in itself a pedagogical skill, and it is necessary to integrate technology, content and pedagogy for pedagogically sound applications of technology rather than treating each of these entities as separate domains (So & Kim, 2009). Hence it is necessary that pre-service teacher understand how ICT tools could support students' learning. In supporting learning and teaching, ICT tools could be categorised as learning tools (sources for information consumption), communication tools, tools for creating and demonstrating knowledge gained, collaborative tools for project or group work, presentation tools to display knowledge in a succinct manner to an audience and assessment tools for formative and summative assessment to find out how well students have learned. Examples of tools in these categories are shown in Table 5.1.

Table 5.1 Types of ICT tools and examples

Types of ICT tools	Examples
Learning tools and resources	Internet, specific discipline learning software; YouTube, Khan Academy; Study Ladder; BBC education websites; podcasts; vodcasts
Communication tools	Email; forums, e.g., Edmodo, Moodle; Blackboard; VoiceThread; Blogger
Creation tools	Glogster.com; MovieMaker/iMovie; Wikispaces; Inspiration; ePortfolio software, e.g., Googlesites, Mahara
Collaborative tools	Wikispaces; GoogleDocs; Popplet.com
Presentation tools	Powerpoint; Prezi; MovieMaker/iMovie
Assessment tools	Hot Potatoes; SurveyMonkey; Quiz Creator

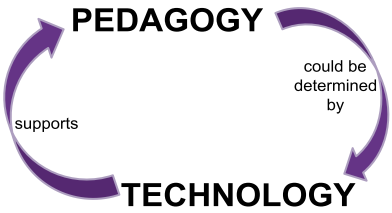

Fig. 5.1 Interdependency of technology and pedagogy on each other

In order to design lessons supported by ICT, teachers will need to know what the available educational technologies are and how their affordances will facilitate the achievement of the intended learning outcomes. For example, if the intended learning in a science experiment is to capture colour changes in different types of reactions, video recording the reactions and inserting the video or hyperlinking to the video (which could be uploaded onto YouTube) in the report would show the teacher that the correct reactions have been carried out, described and explained. It is therefore necessary for pre-service teachers to think through the purpose of adopting ICT and to explore and develop the skills to use them in meaningful ways.

Nichols (2003) stated, as one of the principles of e-learning, that the choice of e-learning tools should reflect rather than determine the pedagogy of a course and that how technology is used is more important than which technology is used. In other words, teachers should let the pedagogy drive the technology and not the technology drive the pedagogy. The argument in this chapter is, however, that it should go both ways (see Fig. 5.1), meaning that unless the teacher knows about the ICT tool and how the functions in it can support the pedagogy, it is more difficult to integrate technology effectively into the pedagogical design of lessons. Just as a content expert will be sufficiently "agile" to move the knowledge around to explain a concept in a variety of ways, a teacher or student who knows the technology in use and its applications well could make use of the available features, singly or in combination to teach or learn and convey his/her teaching/understanding better. For example, in presenting what has been achieved for a team-based WebQuest task, the students will be required to decide on the best way to do that. Do they create a *PowerPoint* or *Prezi* presentation, construct a concept map or digital story, build a wiki or make use of *VoiceThread* where each member of the team will have the opportunity to explain the solution to his/her part of the quest? A well-founded knowledge of the features, limitations and the purposes for which each of these technologies are built for will enable the team to make informed decisions in selecting the one that would most appropriately represent the solution in the manner that they wish to convey. Similarly, teachers would need to be able to distinguish between these forms of presentations and advice their students accordingly. To this end, the argument in this chapter disagrees somewhat with Nichols (2003) principle that suggests "how technology is used is more important than what technology is used" because the "what" often informs the "how" in integrating ICT into education. Hence it is important that in teacher education courses, pre-service teachers are exposed to these types of debates to develop a better understanding of e-learning and what is required in order that ICT is woven effectively into their teaching.

2.4 Concept Mapping as a Means of Capturing Growth in Conceptual Understanding of "e-Learning" During Teaching Training

Concept maps are graphical tools for organising and representing knowledge (Novak & Cañas, 2006). Learners represent their knowledge visually in the form of a hierarchical format or a network of nodes and links. Nodes contain concepts or keywords, usually enclosed in circles or boxes, and the relationships between two concepts are indicated by a connecting line linking the two concepts. Linking words/short phrases are written on the link to show the relationship between the concepts. In this way, a network of keywords/concepts with links between them forms a concept map depicting how the students have understood the topic under study. Apart from using key words to represent concepts or ideas in the nodes, learners could insert images, multimedia or video files to represent their thinking. The tools also have auditory functions for learners to voice record a short statement or an explanation in a node. To show relationships between these multimodal ways of representing concepts and ideas, learners create labelled links between them to further demonstrate and clarify their understanding. Hence concept mapping tools provide flexible means for organising conceptual understanding, allowing students to organise ideas in a logical but not rigid manner, with the option to build on the maps as they progress through their learning.

Concept mapping work is based on David Ausubel's (1968) learning theories. Similar to cognitive constructivism described in Sect. 2.3.2. Ausubel asserts that the learner's prior knowledge is an important factor that influences learning and that meaningful learning occurs only when the new understanding can relate to understanding of concepts that are already in existence in the learner's cognition. The bridging of the old and new concepts learnt can be scaffolded using graphical organisers such as a concept map. Concept mapping software such as *Inspiration*, *Kidspiration*, *Gliffy*, *Conceptshare*, *Cmap and Thinkature* provides the means to communicate the learner's thinking and understanding visually.

Concept mapping is an instructional method to facilitate critical thinking individually or collaboratively (Ng & Hanewald, 2010) by encouraging students to connect new knowledge to their prior learning (Akinsanya & Williams, 2004). By linking new information to their existing conceptual framework, the students construct new meanings to show the transformation of their existing framework and how conceptual changes have occurred. Based on this framework, the conceptual growth demonstrated by the pre-service teachers of their understanding of "e-learning" and its integration into teaching and learning is captured in their pre- and post-course concept maps in this study.

Currently there is no one accepted way of analysing and assessing concept maps. Quantitative approaches such as Hui, Huang, and George's (2008) model make use of a descriptive probability model of concept map formation, along with concept map analyses based on parameter estimates. Qualitative methods could vary, for example Schaal, Bogner, and Girwidz (2010) compared a learner's concept map with an expert's map. This is regarded as a valid and reliable evaluation. Koc (2012) on the other hand makes use of Novak and Gowin's (1984) rubric for evaluating each map based on the points for each meaningful proposition, each valid level of hierarchy, each crosslink and each example shown.

3 Method of Study

3.1 Participants and Data Collection

The research design for this study was descriptive and predictive in nature (Koc, 2012) and based on qualitative data The study sought to investigate the growth in conceptual understanding of "e-learning" of nine case studies through their concept maps construction at the start of the semester (to probe for prior knowledge) and at the end of the semester (to probe for conceptual changes). The nine case studies were second year undergraduate students studying either for their BA/BEd or BSc/BEd double degrees and were part of a class of 53 students undertaking the *Introduction to e-learning* course.

e-Learning is a broad topic and there are a number of ways of viewing it. Unlike science and mathematics learning, where the teacher hones in on the accuracies of content knowledge, assessing how well pre-service teachers have understood about e-learning and its integration into classroom practices is more subjective. The understanding depends on the three dimensions discussed in Sect. 2.3: (1) their knowledge of ICT tools and affordances, (2) their understanding of their students' characteristics and their students' ICT-related practices and (3) their understanding of pedagogical practices that would deliver the intended learning outcomes. The course design was aimed at developing positive experiences for the pre-service teachers through the introduction of learning theories and how young people learn and increasing the pre-service teachers' knowledge and skills in a range of ICT

Table 5.2 Selection of case studies base on final mark for the unit

High achievers (H) (scores 80–100 %)		Medium achievers (M) (scores 65–78 %)		Low achievers (L) (scores 50–64 %)	
Student	Score (%)	Student	Score (%)	Student	Score (%)
H1 (M)	90	M1 (F)	78	L1 (M)	62
H2 (F)	85	M2 (F)	71	L2 (M)	60
H3 (M)	82	M3 (M)	65	L3 (F)	50

F = female; M = male

tools, including the demonstration of how they could be used pedagogically in the classrooms. As a major assessment task, the students created their own ePortfolio to showcase the digital artefacts that they have created for teaching (e.g., a WebQuest in Wikispaces and a complete quiz created in Hot Potatoes) or for demonstrating how acquired content knowledge could be demonstrated (e.g., through digital storytelling or Prezi presentation). As part of their ePortfolios, all students were required to construct pre- and post-course concept maps on their understanding of e-learning and its integration into teaching/learning. They were required to write a reflective piece on why they have constructed the maps in the way they did. For the pre-concept mapping exercise which also probed for their prior views about e-learning, a list of 50 keywords that were related to e-learning were given to the students to help them with the exercise. The concept mapping task was an open task and the pre-service teachers could choose to use a selection of the keywords provided or add their own terms if they were missing from the list. For the post-course concept map constructed at the end of the course, the pre-service teachers were asked to review their pre-concept map and to revise it to convey their understanding of e-learning and its integration into teaching and learning at that point in time.

Koc's (2012) study on pre-service teachers' pedagogical knowledge representations through concept mapping suggested that students 'with high quality concept maps are more likely to have higher course achievement' (p. 665). In this respect, the selection of the nine case studies (three each for high-, medium- and low-scoring students) for this study was based on their final overall mark for the course. Their final marks were based on two assessment tasks: a collaborative task (creating a WebQuest on Wikispaces) and an individual task (construction of an ePortfolio). The underlying assumption is that the high achievers will construct better quality concept maps on e-learning and vice versa. The selection of students and their scores is shown in Table 5.2. For each category, gender balance (at least one male and one female student) and the distribution of scores within each group (lower end, mid-range and higher end) were considered.

3.2 Data Analysis Method

Using the e-learning framework described in Sect. 2.3, the analysis of the pre- and post-course concept maps were conducted according to the three identified

Table 5.3 Analysis method of pre-service teachers' concept maps on e-learning

Dimensions of e-learning and its integration into teaching and learning that pre-service teachers need to demonstrate understanding in	Analysis of concept maps	
	Category	Examples of keywords and connection of concepts
1 Knowledge of technology tools and affordances	Group tools without differentiation	See Fig. 5.2a
	Group tools in pedagogical categories and show explicit use	See Fig. 5.2b
2 Understanding of the characteristics/practices of students and how they learn (i.e., learning theories)	Demonstrate understanding of students' characteristics	Digital natives or similar terms; mobile learners; lead e-lives
	Demonstrate understanding of students' practices	Informal learning; social networking; online activities; use mobile technologies
	Apply learning theory	Constructivism; Multiple Intelligences
3 Understanding how to embrace ICT to facilitate and support the pedagogy	Demonstrate the integration of ICT to facilitate teaching and learning	What and how ICT support independent learning (see also Fig. 5.4)
		What and how ICT support collaborative learning

dimensions that the pre-service teachers would need to be able to demonstrate understanding about e-learning and its integration into teaching/learning. As shown in Table 5.3, the three dimensions were further broken down into categories for the analysis with examples provided for each category. For example for the "Knowledge of technology tools & affordances" dimension, it was broken down into two categories: whether the students were able to differentiate the tools into their pedagogical uses or not. For example Fig. 5.2a showed no differentiation of the tools that were grouped collectively as "programs and learning tools". Figure 5.2b showed some differentiation of the tools and the linking to their pedagogical uses. For example, *Inspiration*, *Photoshop* and *MovieMaker* are visualisation tools and that *MovieMaker* could be used for creating digital stories.

4 Data Analysis and Discussion

Apart from student H2 who used the spider format for her pre-course concept map, the rest of the case studies made use of the nodes-and-link format. Only student L3 used the hierarchical structure for both her concept maps, while the rest of the case studies used networked mapping that showed key concepts being interlinked between several other concepts/keywords in webbed forms. This is consistent with the whole class' choice of the presentation format of their concept maps where less

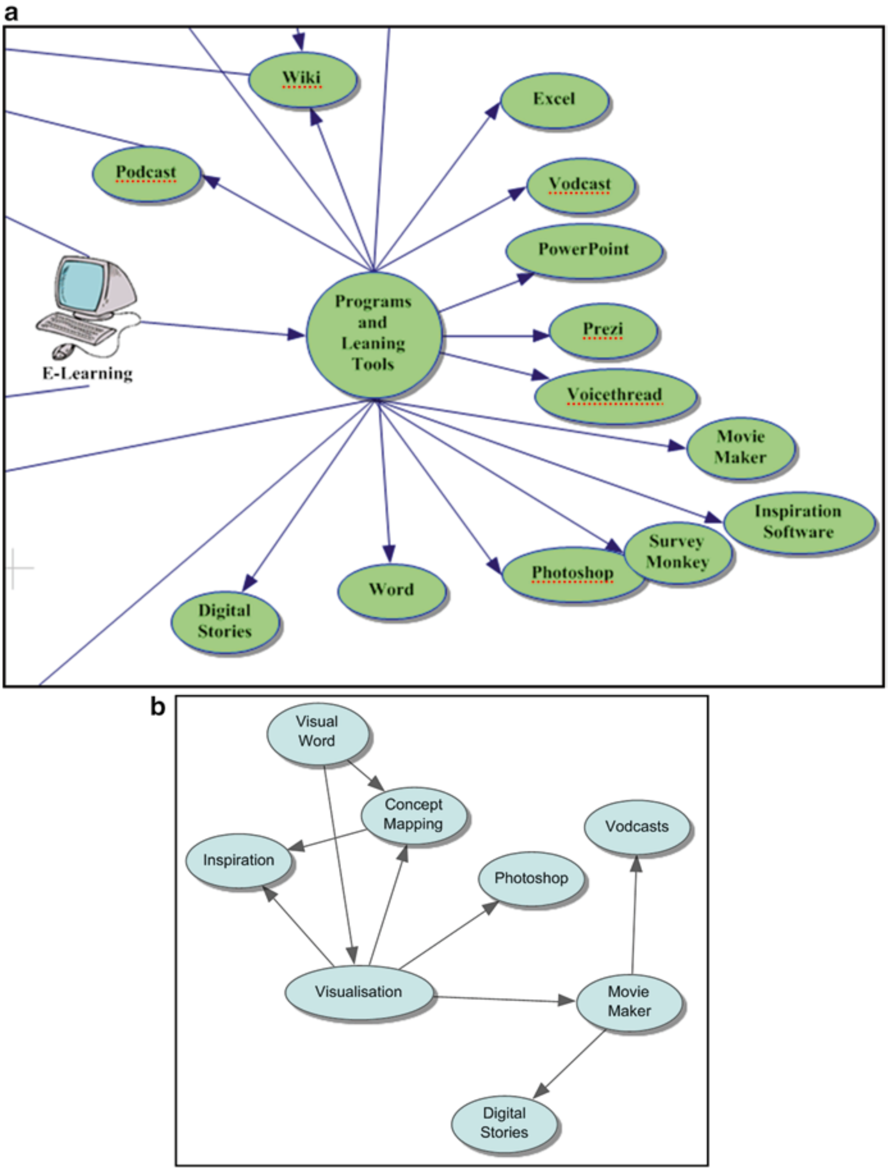

Fig. 5.2 (**a**) Grouping tools without differentiation. (**b**) Group tools in pedagogical category and show explicit use

than 18 % used the spider format for their concept maps. Due to the fact that linking words cannot be placed in the spider structure, the nodes-and-link structure is a better presentation format to convey more meaning across to the reader.

As shown in Table 5.4, almost all the case studies were able to group tools in pedagogical categories that showed explicit use of the technologies, similar to the

Table 5.4 Results of the analysis of the case studies' concept maps and their understanding of e-learning and its integration into teaching/learning

Dimensions of e-learning and its integration into teaching and learning that pre-service teachers need to demonstrate understanding in	Analysis of concept maps (category)	PRE-course concept maps									POST-course concept maps								
		(High) Student			(Medium) Student			(Low) Student			(High) Student			(Medium) Student			(Low) Student		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1 Knowledge of technology tools and affordances	Group tools without differentiation					x		x	x	x								x	x
	Group tools in pedagogical categories and show explicit use	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
2 Understanding of the characteristics/practices of students and how they learn (i.e., learning theories)	Demonstrate understanding of students' characteristics																		
	Demonstrate (implied) understanding of students' practices	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	
	Apply learning theory											x	x		x				
3 Understanding how to embrace ICT to facilitate and support the pedagogy	Demonstrate what and how ICT support independent learning		x		x						x	x		x	x			x	x
	Demonstrate what and how ICT support collaborative learning		x		x						x	x	x	x		x	x		

example shown in Fig. 5.2b. However, none of the case studies paid attention to the characteristics of the students that they will be teaching in both pre- and post-course concept maps. This is in spite of a dedicated lesson on this topic. There was only one student (not one of the case studies) in the whole class who added “digital natives” in his post-concept map, showing explicitly the practices they undertake, i.e., social media networking and being part of online communities. The case studies except student L3 showed “implied” understanding of young people’s practices because they were able to link “communication” to social media tools, the use of mobile technologies and informal learning. As part of the task was to show integration into the learning of the students they will teach, the implied assumption of understanding of practices is valid. As the case studies were second year undergraduates aged between 18 and 19 years old, it is not surprising that they could demonstrate this aspect of e-learning well. Even though the lectures covered what research says about how young people learn and various other learning theories, the case studies’ concept maps appeared to focus mainly on the technologies and how they could be categorised or used to support either processes of learning (e.g., research, information gathering) or as a strategy for learning (e.g., as visual or audio tools). Only students H2 and M2 made explicit references to the learning theory of multiple intelligences by adding “learning styles” as a node, as shown in Fig. 5.3. (Note that it is not possible to show the full concept maps of the students due to the enormity of the maps, hence only sections are shown in this chapter).

The results in Table 5.4 shows that there is growth in the thinking about e-learning and its integration into teaching/learning for all the students, as indicated by the ability to show more elements of required understanding in the post-concept maps (as indicated by the increase in “x” in Table 5.4 for the post-concept maps).

As shown in Table 5.4, the comparison between pre- and post-course concept maps shows a bigger distinction in the demonstrated understanding of the topic between the high/middle and low groups. The level of distinction is informed by the level of increase in the number of elements identified in the post-course concept maps and the quality of the work of the students. The distinction between the high and middle groups of students appears to be less except for student M3. Student M3 scored 65 %, the lowest cut-off score in the medium category and the distinction between him and student L1 was less obvious. Hence a better design for future comparison studies is to select students with distinctive mid-range scores for each category (e.g., medium ability students with scores around 75 % and low ability students with scores around 55 %) rather than span the range of scores within the category.

There is, however, a distinction in the quality of the concept maps between high achievers and middle/low achievers. The representations by the high achievers were more sophisticated. For example Fig. 5.3 shows H2’s ability to link “auditory learning” to appropriate key concepts to demonstrate both independent learning and collaborative learning and the tools to support these types of learning. Similarly, the quality of H1’s representation of independent learning (see Fig. 5.4) showing the processes of and tools to support independent learning is better than most of the other concept maps. The quality of the medium group’s work is mixed with the higher scorers within the group producing clearer views of e-learning. For example

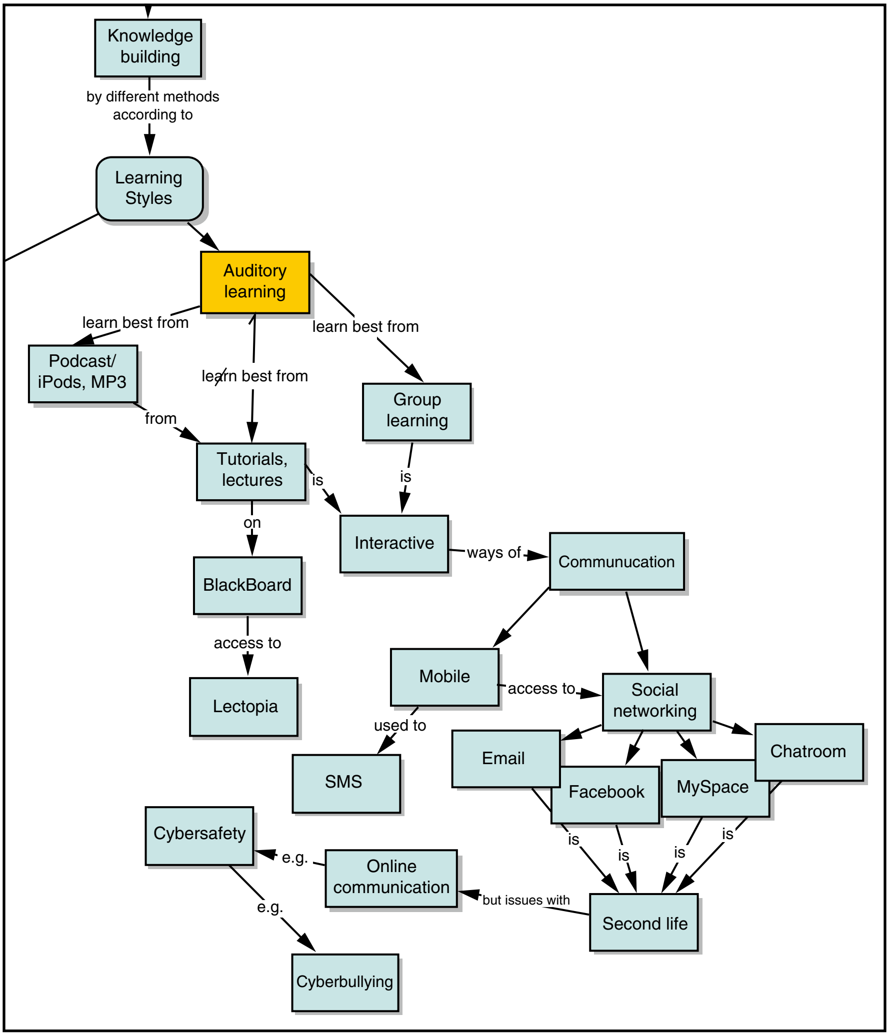

Fig. 5.3 A screenshot of a section of H2's post-course concept map

in Fig. 5.5, in the post-course concept map of M2, she looked at e-learning from the formal and informal perspectives and the only one in the class who embraced mobile learning and ubiquitous computing into her concept map.

The quality of the concept maps of the lower achievers is low because the representation of the key concepts/words and the links between them are less clear or incorrectly placed relatively to each other. For example in Fig. 5.6, without the linking words the relationships between the key words are unclear such as how multiliteracies relate to tutorial or research in the map. Another example is L3's post-concept map which was a relatively big improvement from the pre-concept

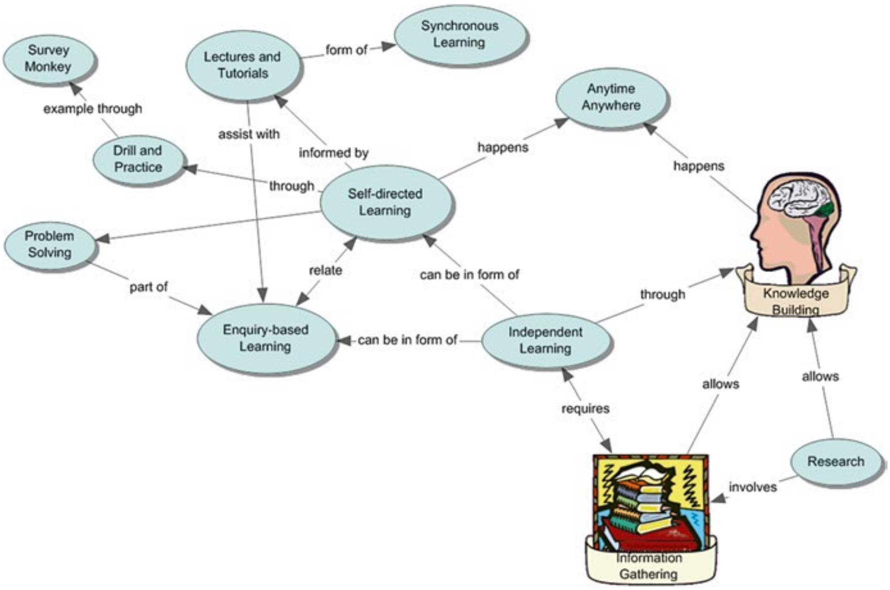

Fig. 5.4 A screenshot of a section of H1's post-course concept map showing the processes and tools supporting independent learning

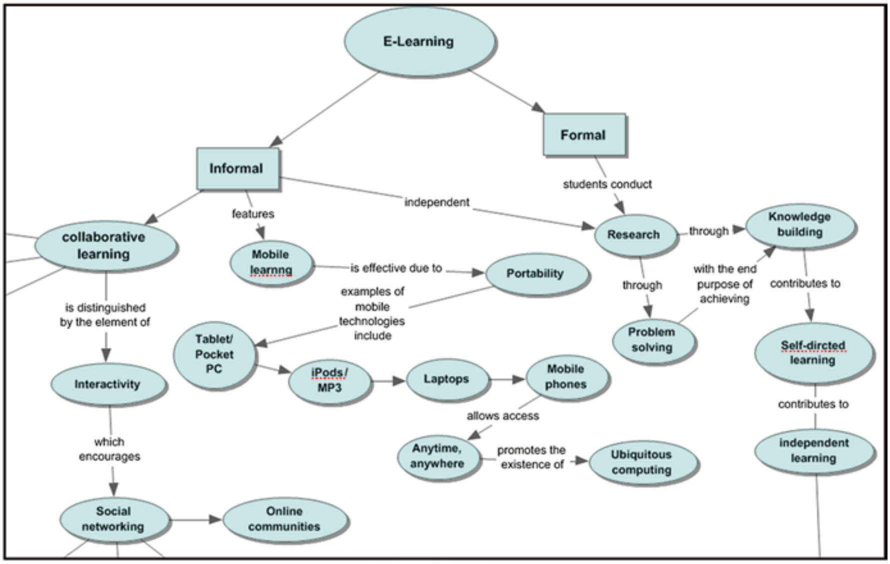

Fig. 5.5 A screenshot of a section of M2's post-course concept map showing e-learning branching into formal and informal learning

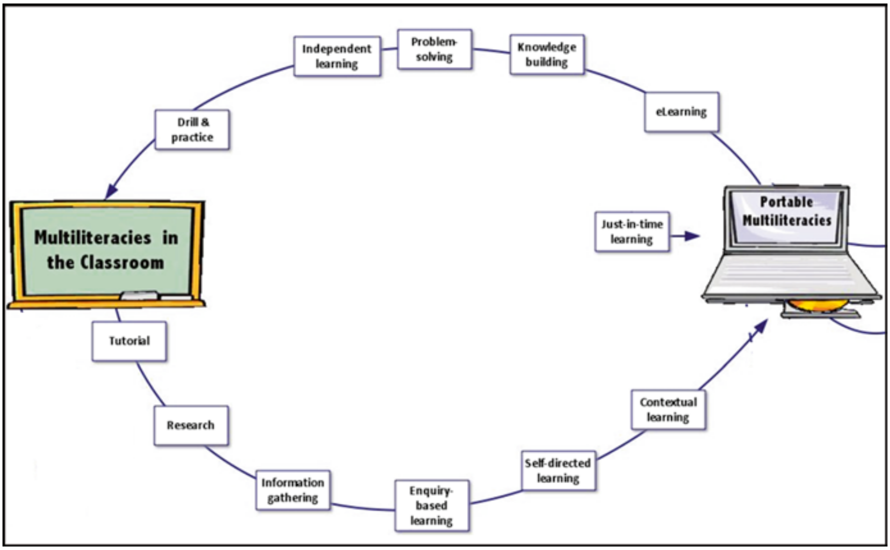

Fig. 5.6 A screenshot of a section of L2's post-course concept map

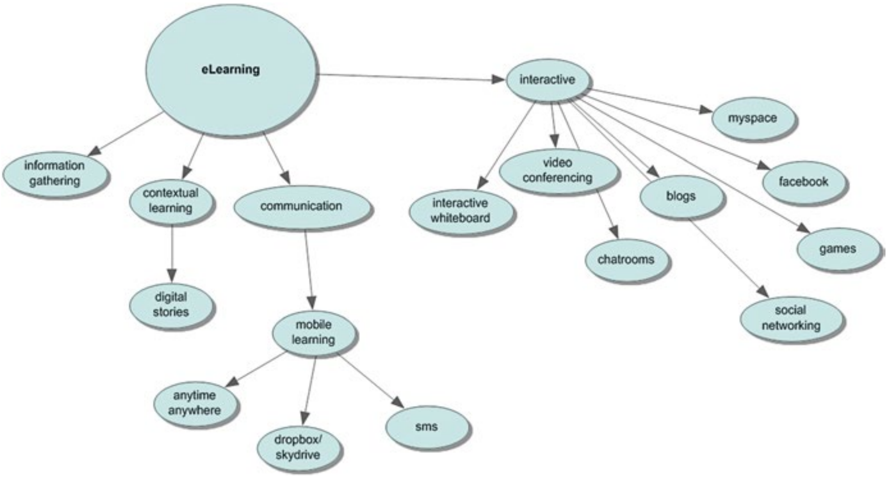

Fig. 5.7 A screenshot of a section of L3's post-course concept map showing mainly categorization for e-learning

map but only showed the basic level of thinking, that is, the hierarchical format that he used (see Fig. 5.7) did not show the complexity of the topic as demonstrated by the webbed concept maps of the high and medium achievers.

Inaccuracies were evident in the concept maps of all the three groups of student, e.g., high achiever H3 linking "database" to contextual learning in both pre-and post-course concept maps.

5 Conclusions, Limitations and Implications

The study showed that all nine case studies were able to demonstrate varying degrees of improvement in their conceptual thinking about e-learning and how the use of technology could be integrated into their teaching and their students' learning. Hence concept mapping is a useful tool to map visually the pre-service teachers understanding of topics such as e-learning. For teacher educators, these maps provide a quicker means of assessing where students are at without having to read long descriptive texts that students write to convey their understanding. As the research was limited to only nine case studies and the patterns of thinking are not distinctive, particularly between the high and medium scoring groups, the results cannot be generalised. The results, however, support Koc's (2012) assertion that high performers were able to construct clearer and better-connected concept maps. Another limitation of the study is that the open nature of the concept mapping tasks required that "judgement calls" be made in instances of grey areas for the analysis of the concept maps. Instructors will need to be consistent in assessing the maps in this respect.

An implication of the research for teacher education is to use concept mapping as formative assessments rather than summative as in the case of this study. The large number of key words that students tried to accommodate in the post-course concept maps made it difficult to fit on a page and for the instructor, it could become onerous work to assess when the map becomes too big and there is the need to scroll in various directions to view the map (as in the case of the concept maps of this study where the average number of keywords that students used was 47). Getting the pre-service teachers to construct maps after teaching each dimension of the topic would be a more practical and effective way to assess their understanding. More research into different formative assessment styles using concept maps in different subject domains and topics is required.

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Chapter 6
Concept Mapping in Graduate Education

Variety and Depth of Student Projects

Scott R. Garrigan

Abstract This chapter describes four informal case studies in concept mapping with graduate education students and in-service teachers using CmapTools (or simply Cmap), a concept mapping system with a particularly rich set of affordances. Three studies describe actual student applications of concept mapping using Cmap in three different graduate courses in Lehigh University's College of Education and in Wilkes University's Graduate School of Education, both in Pennsylvania in the USA. The fourth study describes the author's experience in introducing Cmap as a concept mapping application for K-12 student use to about 1,000 K-12 teachers through regional hands-on workshops and national conference presentations. The aim was to raise teachers' awareness of the potential benefits of concept mapping and to introduce them to powerful, free, concept mapping software for their classrooms. Findings indicate that teachers may adopt concept mapping if they recognize a compelling need to do so, and they tend not to understand the potential benefit and specific uses without intensive and extended professional development.

Keywords Cmap • CmapTools • Concept mapping • K-12 • Graduate education • Teacher education

1 Introduction

The author has introduced concept mapping software to over 1,000 in-service teachers and graduate teacher education students over a 7-year period as part of graduate courses and in-service workshops on instructional technology. Many of the K-12

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schools in which these teachers work (or will work) have licensed *Inspiration* or *Kidspiration* concept mapping software, but most teachers seldom or never use concept mapping software. As a former school district technology director, the author licensed this software for nearly 10,000 students across 12 elementary and middle schools and initiated training for hundreds of teachers. In retrospect, relatively few of those teachers have integrated concept mapping into their classroom in meaningful ways, and relatively few of the students have had the opportunity to deeply learn concept mapping.

Since becoming a teacher educator, the author has sought ways to introduce and train educators to use concept mapping as a valuable knowledge organization tool for their students. This chapter discusses the goals, venues, approaches, successes, and failures of four different models of concept map training for educators. The discussion uses the terms *knowledge mapping* and *concept mapping* in the following way. *Knowledge mapping* is used to reference the broader ideas of the connected way that knowledge may be organized; *concept mapping* is used to reference smaller-scale or more limited use of the ideas such as using concept mapping software to organize the ideas in one unit of K-12 study.

1.1 The CmapTools Application

The CmapTools knowledge mapping system was selected for this task for several reasons. Cmap empowers teachers and students because it is free for nonprofit use and can be conveniently downloaded to Windows or Macintosh computers at home or at school from IHMC, the Institute for Human and Machine Cognition (http://ihmc.us/cmap). Additionally, Cmap provides affordances that make it a particularly flexible and powerful tool for users from 10-year-olds to adult lesson planners and curriculum designers (Cañas, et al., 2004). These affordances, such as remote collaborative editing, external linking, hierarchical map structure, graphics integration, rich notation, powerful sharing, and convenient conversion to Web pages, will be described in greater detail in the sections below. The depth and power of the knowledge mapping system may be glimpsed through NASA's use of the system to plan the Mars missions of the Spirit and Opportunity rovers through more than 100 linked concept maps with live links to thousands of external links and documents (NASA, 2001).

The popularity of Cmap is best seen through the thousands of shared concept map sites individuals and institutions have created through the global Cmap system of public servers. As represented by public educational institution sites on these servers, the Cmap system is especially widely used across educational levels from elementary school through graduate study in North America and Central and Southern Europe. The system is also in broad use in Central and South America. These public sites of shared Cmaps can be viewed and accessed through the CmapTools application. As an intentionally global system, IHMC provides Cmap in over 15 languages and publishes a map to convey the global distribution of its use (http://www.ihmc.us/cmaptools.html). Educational institutions that prefer to develop private Cmap collaborative repositories may download the free Cmap server software from the CmapTools Website.

1.2 Literature Review

This chapter is composed of the reflections of an informed practitioner; it is not intended to be a formal research study. A very extensive literature on professional development exists that has consistently found that teacher behavior does not change through “one-shot workshops.” Instead, school-based leadership and extended support through coaching or other means have been found to be effective. That said, most school districts do not follow this model, or, if they do, concept mapping is not a priority topic.

A very brief review of two studies in professional development for concept mapping may provide some context for the rest of the chapter. Rye (2000) worked with secondary science teachers who chose to attend extended, grant-funded summer workshops through his exemplary Health Sciences and Technology Academy. Some teachers chose to continue their concept map training through his graduate course at West Virginia University. His sample consisted of 18 teachers who received intensive, extended training in Inspiration concept mapping software and 26 teachers who received less intensive training. All of the teachers’ schools had Inspiration licenses, and all (or nearly all) of the teachers were familiar with concept mapping prior to the workshops. The study found that after professional development, these teachers understood the value of concept mapping, knew how to use Inspiration software, and conducted basic concept mapping activities in their classrooms. In other words, under the ideal circumstances of self-selected teachers, extensive training through a funded summer academy and a university graduate school, and school licenses for the commercial software, teachers seemed to make effective use of concept mapping software. Rye’s model points out best practices in professional development for concept mapping, but the ideal conditions of his study argues that his model may not scale up to meet the needs of real teachers in less-than-ideal environments.

Kilic, Keleş, and Sağlam (2012) surveyed 24 elementary teachers from across Turkey who had “been instructed about concept maps and … constructed concept map examples” (p. 85). Their survey questioned teacher attitudes and beliefs about concept maps, but it did not explore whether teachers used concept maps in their classrooms, how they might be used, or how deeply they might be used. Both studies had small samples and seemed to address only basic ideas and uses in concept mapping. Neither study appeared to address the broader ideas of teacher understanding of knowledge mapping.

Concept mapping is a powerful way to construct, organize, and communicate knowledge, and tools like Cmap provide powerful affordances to hide detail until a viewer wants to expand it, to hierarchically link submaps as well as concepts, to link to nearly any resource on the Internet, and to export concept maps for global Web accessibility. The reflections expressed in the case studies below describe the author's exploration of ways to deepen educators' awareness, skill, and use of concept mapping software from simple applications to rich, deeply personalized applications.

1.3 Overview of Cmap Training

The four case studies below describe the introduction of educators and graduate students to CmapTools *as a powerful tool for learning*. The focus of each case study was generally on practical K-12 classroom applications rather than on knowledge map theory of concept, proposition, and structure. While not formally emphasized, the ideas of concepts, propositions, and structure were used in natural, authentic ways to carry out learning and presentation tasks. Although the classroom applications did not emphasize knowledge mapping theory, they did emphasize a constructivist epistemology that was a good fit for thinking about and applying concept map systems. In simplistic terms, the use of concept maps in classrooms was intended to provide individual, meaningful learning affordances that may help to replace traditional rote learning practices. Using links and resources, the concept map becomes a kind of portfolio that can show what that student has learned and how she has connected newly acquired knowledge to her existing knowledge base.

The first case study describes the introduction of Cmap to master's and doctoral students in an overview course on classroom applications of educational technology. These adult students were typically certified teachers or were in a teacher certification program. Over the course of 14 class meetings, about three hours of hands-on instruction were devoted to Cmap. Students were expected to creatively apply Cmap as one of their weekly assignments. Success was mixed in that students were able to learn the basic operations of concept map building, but most were not able to apply concept mapping to their classroom lessons in ways that they wanted to implement with their own current or future classes. A few of these graduate students have implemented Cmap with their classes, but they represent fewer than 10 % of the students in this course.

The second case study was an elaboration of the first case study in which graduate students selected one of the educational technologies introduced through the course to elaborate as a final course project. This elaboration expected that they would independently research the technology system and its affordances. For the final project, the student would develop and present a model classroom application using the technology and write a narrative discussion of what and how her students were expected to learn from the experience. About 10 % of these graduate students selected Cmap as their final project, and their work was significantly more elaborated than that seen in the first case study. Their projects demonstrated a deeper theoretical understanding of knowledge mapping, a familiarity with more of the affordances of Cmap, and a more integrated and creative application of Cmap to authentic K-12 learning.

The third case study discusses the author's attempt to deeply integrate concept mapping into the core of a graduate course on instructional design. This course enrolled more serious students with about half in doctoral study. Cmap was used to help visualize the flow of design processes and decisions, and appropriate affordances were introduced at several times throughout the course through a scaffolded approach. Concept maps were developed both individually and collaboratively, and they were required components of several major assignments. This deeper engagement in authentic design tasks seemed to result in successful and creative application of concept mapping for all students. It was their success that prompted the author's reflections that resulted in the taxonomy of case studies from which this chapter emerged.

The final case study reflects on the introduction of Cmap to nearly 1,000 teachers who participated in the author's workshops and presentations on classroom applications of educational technology. These experiences ranged from 1-hour hands-on guided instruction to 10-min demonstrations of Cmap. In all of these shorter sessions, the intent was merely to inform teachers about a freely accessible concept mapping system that they could use with their students. Most learned that this concept mapping tool was available, but the teachers generally did not develop an understanding of how and why concept maps would be used for learning. Those already using a system like Inspiration or paper concept maps generally did not appreciate the additional affordances of Cmap enough to change their classroom practice. This case study reinforces the idea that short-term exposure to ideas and tools does not tend to change the classroom behavior of in-service teachers.

In each case study, the theory of knowledge mapping was informally presented as "learning something new by connecting it to what you already know." In other words, concept mapping was advanced as a way for students to learn in a deeper, if more individual, manner. Graduate students and teachers had no trouble learning the basic mechanics of creating a simple concept map with CmapTools, but brief exposure to the ideas and the Cmap application was generally insufficient for them to understand the conceptual affordances of knowledge mapping.

2 Case Study 1: Teaching Cmap as an Instructional Technology

Over a 5-year period, the author introduced concept mapping as an instructional technology to over 100 K-12 teachers and other master's and doctoral students enrolled in "classroom applications of technology" courses. The courses were offered at two universities in Pennsylvania, and some of the master's courses were fully online. It is common for both undergraduate and graduate teacher education programs to offer such courses, but few of the graduate students in the author's classes were familiar with concept mapping, and very few used concept mapping with their K-12 students. Informal inventories suggested that about 25 % of these practicing teachers were familiar with concept mapping and popular software such as Inspiration or Kidspiration. Only about 8 % of these teachers actually used concept mapping with their students, although this usage appeared to vary dramatically from school-to-school or district-to-district. For example, a survey of one middle school faculty found that none of the teachers were familiar with any concept mapping software, and that only three teachers used paper-and-pencil concept mapping in their classes. Although there are counter examples of schools that provide concept map training to all of their teachers, it appeared that there is a gap both in K-12 teacher awareness and in the classroom use of knowledge mapping concepts and software.

In these graduate courses, there were two main goals in the introduction of concept mapping as an instructional technology. The first goal was to nurture in teachers the idea of knowledge mapping as a powerful "tool to think with." In lecture and discussion, concept maps were portrayed as a brain-congruent way for students to relate new concepts to existing knowledge and to represent these relationships in a visually mapped structure. It was suggested to the teachers that this approach captured some of the fundamental constructivist principles of learning.

The second goal was to build teachers' awareness of the affordances offered by modern concept mapping systems such as Cmap. Since they had little previous background on which to base this awareness, each affordance was presented, demonstrated, and made concrete through hands-on creation of concept maps in a scaffolded sequence of activities.

2.1 The Six Affordances of Case Study 1

The following six affordances of Cmap were taught to the teachers and other graduate students through presentation, guided practice, and independent practice. These activities spanned two sequential class periods one week apart. Roughly three hours of class time and one or two homework assignments were devoted to concept mapping in these graduate classes. The specific six affordances covered are listed below in the order in which they were taught:

1. *Node-and-link structure*. Teachers quickly understood the hierarchical structure of nodes and links on a procedural or how-to-do-it level, but few teachers identified applications for these ideas in their own classrooms that they wanted to try. Even fewer teachers seemed to generalize concept map structure to larger ideas concerning the structure of knowledge (such as the structure of knowledge in their own discipline).
2. *External links*. Cmap provides ways to link any concept or link node to outside resources like Web pages, images, videos, audio files, or documents in many formats like pdf, MS Word, or Excel spreadsheets. With guided practice, all teachers were able to link nodes to external Websites.
3. *Collaborative editing*. Cmap is one of a very few concept mapping applications that affords simultaneous, collaborative editing. Since collaboration is such a

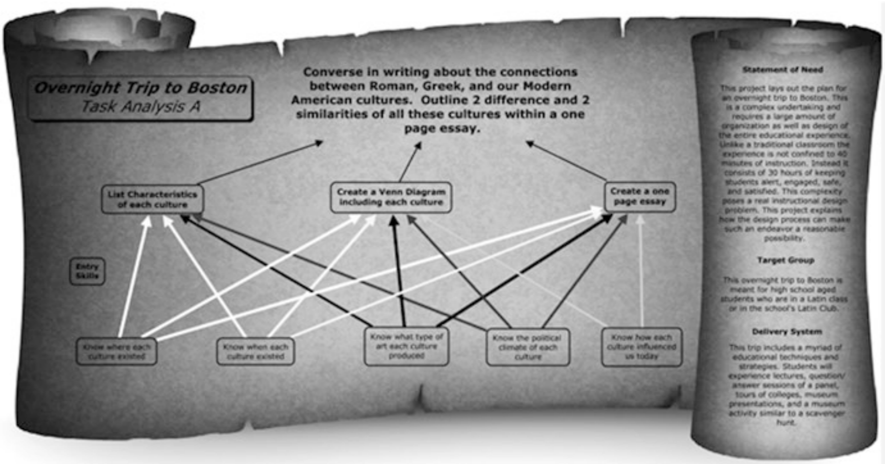

Fig. 6.1 The scroll background graphic reinforces the classical Greek and Roman motif of a Cmap concept map of the instructional plan for a field trip for a high school Latin class. Text fields are used along with traditional concept map nodes and connections (image courtesy of Tiffany Snyder)

large part of the team-based planning and development process in the real world, it seemed important to have teachers personally experience this way of working. Most teachers were able connect to a collaboratively edited concept map, but few seemed to understand or effectively contribute to the collaborative process. Essentially none of the hundreds of teachers to whom this affordance was introduced actually used collaborative editing themselves or with their own students.

4. *Conversion to Web page*. A Cmap concept map is automatically converted to a Web page when it is saved to a Cmap server. The Web page version of these concept maps retain most of their information organization capability, supporting the source concept map's hot links to submaps, Web pages, videos, images, and documents. The Cmap home page was offered as a powerful example of a concept map as Web navigation system, and the Web-accessible NASA Mars hierarchical concept maps demonstrated Web-based knowledge organization (NASA, 2001). As with collaborative editing, teachers did not independently use this affordance, perhaps because the increasing cognitive complexity of the larger Cmap system was too much for them to internalize in 1 or 2 weeks.
5. *Image integration*. Cmap affords the inclusion of images as nodes or node backgrounds and as background images for the entire map. In this way, concept maps can be made more visually informative, professional, and aesthetic. Teachers who used Inspiration/Kidspiration in their classes asked if Cmap had built-in clip art like the programs they were used to; they were disappointed when told that Cmap images must be selected and linked rather than chosen from a "canned" gallery of cute images and icons. Few, if any, teachers used this affordance of Cmap in the graduate class or independently. See Fig. 6.1 above as an example of rich graphic integration in a concept map.

6. *Minimal barriers to educational use*. Teachers immediately appreciate that Cmap is free for institutional and individual educational use, and it runs on any Windows or Macintosh computer. Cmap server is also free for educational institutions, but teachers typically have little experience or interest in servers. Commercial software requires funding, approvals, and license management presenting hurdles that Cmap completely avoids. In addition, Cmap may be used by students on their home computers at no cost, which can empower students with their own thinking and collaboration tools. Surprisingly, teachers seemed to have little interest in empowering their students outside of school. The free nature of Cmap appeared to be the most salient feature of all six of the affordances to which the teachers were introduced.

2.2 Discussion of Case Study 1

The discussion of this informal case study of the introduction of Cmap to teachers and other students in a graduate educational technology course will focus on three factors: the participants, the teaching content and methodology, and the results.

There were four general categories of students in these graduate courses: K-12 teachers in every subject from physical education to mathematics, graduate students pursuing a career change into education, those pursuing a career change into instructional design or technology, and those pursuing related doctoral study. Some of the students took the course to fill academic credit requirements, some to fill credits required for their next salary step, and some to seriously learn about ways that technology can support teaching and learning. While all were familiar with common technology applications like Microsoft Word, PowerPoint, Facebook, and Google Search, very few had a strong technology background. Some had experience with educational technologies like iMovie or interactive whiteboards, but very few had used low-cost, cross-platform, empowering tools like Cmap designed to help learners visualize ideas—to give them *tools to think with*.

As a class, the students tended to have more practical than theoretical interests. They appeared more interested in easy-to-use, structured approaches to specific topics in their curriculum and less interested in the creative applications of empowering technologies. There are several plausible reasons why teachers may have this relatively narrow focus. They report that the current focus on basic academic standards and high-stakes testing requires them to adhere strictly to the prescribed content. They seem to unquestioningly assume that their teaching must be traditionally rigorous rather than seeking to creatively apply new approaches. Not every teacher or graduate student in the courses fits these broad generalizations, but the generalizations have been repeatedly supported by student comments and questions.

Some of the teachers report that they have limited access to technology, and they have difficulty imagining how these educational technologies can be used. Others suggest that the required technology is unavailable at school due to budget cuts or at home due to low-income. Their limited experience and expertise with technology may make it difficult for them to imagine how technology tools can empower thinking for themselves or their students.

The course content on concept mapping focused on the most accessible and empowering affordances of the Cmap system. The instructional approaches allowed them to achieve short-term success with completing basic Cmap tasks such as creating a concept map with hot links to external resources. The scaffolded activities permitted students to gain an awareness of the Cmap affordances but did not motivate them to independently explore the system further or to use it with their classes.

The results were somewhat disappointing though not unexpected. The student course evaluations gave high marks to these courses, especially in that they found the course content to be interesting and well taught. Students gave lower scores to the questions regarding how useful they found the course content to be. These results were mirrored by both the university evaluation and the instructor-required self-evaluation. One informal conclusion was reached and two hypotheses were generated. The author concluded that the students were effectively *introduced* to concept mapping and Cmap and that nothing more *should* be expected of such an introductory course. The plausible hypotheses suggest two ways to increase student understanding of knowledge mapping and to improve their facility with Cmap's many powerful affordances. The first is that deeper student engagement may emerge if students are permitted to choose which system(s) they would like to explore in greater depth. The second is that deeper student engagement may emerge if students use concept mapping throughout a course as a way to map their developing knowledge. The first hypothesis was informally tested in case study 2, and the second hypothesis was informally tested in case study 3.

3 Case Study 2: Deepening Cmap Learning Through Course Project

The results from the first informal case study suggested that graduate students in an introductory course on classroom applications of instructional technology gained only limited awareness and skill in the application of concept maps to teaching and learning. While this may be an expected outcome of such an overview course, it raises the question of how teachers or graduate students may develop a deeper understanding of concept mapping for their own and their students' use. Following the first hypothesis generated from Case Study 1, a section of the graduate course was taught that required students to choose one instructional technology from the course to elaborate as a final project. The final project was to demonstrate both the skills they learned in taking appropriate advantage of the technology's affordances and a creative educational application of the technology. This second case study explores how students who chose Cmap as their final project technology deepened their understanding and skills.

The course final project added several factors that served to deepen knowledge map understanding. The first was that students were intrinsically motivated to deepen their learning because they had freely chosen this topic and were therefore invested in it. Whether they made their choice based upon a potential practical classroom application or because they were more interested in Cmap technology than the other options is less relevant than their act of personal choice. They had some kind of purpose or goal in mind in making this choice that could drive their learning to deeper levels.

The second factor that helped to deepen their understanding was the expectation that their project had to demonstrate their deeper knowledge and skills. Another factor was that they had to demonstrate their project to the class, teaching other students what they might learn from further study of Cmap. A final factor that deepened their knowledge was the additional intensive time they devoted to Cmap. The 2 or 3 weeks students spent on their final projects tripled or quadrupled the time they spent learning Cmap in weekly class assignments. The final project was an independent study in that students needed to continue their learning from where the class study ended. The project was to be a working example with a supporting narrative describing the project in academic terms and format. Students could not just “talk” about what they would like to do; they had to demonstrate their functional model. They would need to demonstrate affordances in the Cmap system that were not covered in class.

Students used three sources to research their Cmap project. Several students read publications of Novak, Cañas, and others whereby they gained insight into the larger domain of knowledge mapping. While this was no more than an introduction to these bigger ideas, it was more than had been achieved through prior short-course assignments. In their presentations, some students demonstrated an even deeper understanding and appreciation of the knowledge mapping concepts that the instructor expected. This connection to the academic literature could also be of future help to the doctoral students, but no doctoral students have so far chosen Cmap for their final project.

The best source for exploring the affordances of Cmap is the remarkable Cmap help system. Many computer applications have linear user manuals, some are even well indexed, but Cmap has a very clear system that gives visual and descriptive help on each feature of the system. This Web-based help system is accessed from the application’s Help menu; this makes it convenient because Help is always only one click away. The striking clarity of Cmap help is one reason that students were able to effectively integrate several of Cmap’s more complex affordances into their final projects. With this help system, students knew exactly where to find how-to-do-it information when they needed it, and it guided them effectively as they strove to expand their skills.

The final source for research was YouTube in which a search for “Cmap Tools Tutorial” yielded over 300 hits. The YouTube tutorials generally had a voice narrative describing the affordance that was being visually demonstrated. These three sources complemented one another in that the academic papers provided a broad intellectual context, the help system provided a searchable, scaffolded, step-by-step

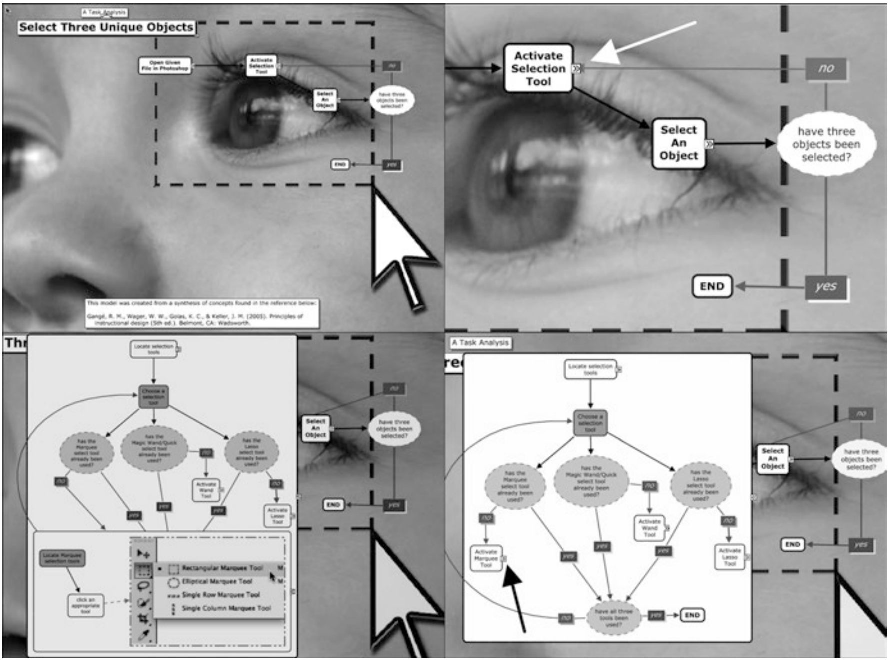

Fig. 6.2 This four-segment series demonstrates how advanced students used Cmaps *expand* and *collapse* functions to display increasing levels of detail on demand. Clockwise from top left, (1) the clear, artistic submap page, (2) close up of the node that will expand when clicked where the *small white arrow* is pointing, (3) a richly detailed map of subtasks now covers the task node that was expanded, and, when the node pointed to by the *black arrow* is clicked (4) another collapsed node expands to display additional detail over the expanded node (image courtesy of Benjamin Hammel)

reference on every affordance, and YouTube provided narrated videos that showed the flow of actions with simultaneous explanation.

A typical student final project showed Cmap as the tool to develop a concept map demonstration or lesson for their students. All of the final Cmap projects included appropriate nodes and links. Color coding was frequently used as a key to related concepts or levels. Hierarchical submaps were generally used with effective navigation back to the top-level map. Links to external resources were heavily in evidence as was the simple incorporation of images into some of the nodes. Some final projects were saved to a Cmap server and were demonstrated through the resulting linked Web pages that were created. None used the synchronous collaboration feature. Students did use one or more of at least three affordances that were not covered during the whole-class study. The most common feature was the affordance to expand collapsed nodes to show greater detail on demand and to collapse the nodes when the higher level of detail was not needed (see Fig. 6.2). A second feature was the mouse-over information that could be added, again to add information on demand that is usually hidden to minimize clutter and cognitive confusion.

The feature that most surprised and impressed the class was the affordance to build an auto-running presentation with recordings of the creation and linking of nodes. Combined with a live narration, this freed the speaker from clicking links while trying to concentrate on communicating ideas to the group. None of the students used Cmap for their final projects in a *professional* manner, but they all had moved well beyond the introductory level of the rest of the graduate class.

All of the students who chose a Cmap final project enjoyed what they learned, and the class was impressed by their presentations. It is clear that this independent study of a chosen technology was an effective learning design. It is unclear whether students assigned to complete a Cmap final project without having chosen it themselves would have learned or enjoyed it as much. It is also unclear whether the students who completed Cmap final projects continued to use the system for their personal or classroom use. The final project approach succeeded in deepening student knowledge in a way that impressed the students but did not entirely satisfy the instructor. Students still did not view Cmap as a powerful nonlinear organization and presentation tool because they focused on one or two "wow" features without balancing the affordances effectively and dramatically in a way that can be done with few other concept map tools. Case Study 3 was an attempt to further deepen and integrate Cmap through knowledge mapping activities that extended throughout an instructional design course.

4 Case Study 3: Deep Integration of Cmap into Instructional Design Course

In Spring, 2012 and 2013, the author taught a graduate course on introduction to instructional design. Unlike the courses discussed above, this is an integral course to a master's program in Instructional Design and Technology and a foundation course of several doctoral programs. A program requirement of the course was that it must focus on providing students with a solid foundation in instructional design theory and methods. Cmap seemed to be an ideal system for this course to visualize and develop the flow of the instructional design processes from event to event. The affordances of Cmap would permit instructor and student to clearly show the conditional flow in instructional branching and the iterative flows as events are repeated or revisited. The Cmap affordances for expanding high-level nodes into submaps or expanded nodes and the ability to link arbitrary digital external resources seemed to add a strong knowledge mapping framework to the course. This strong framework may offer the potential to ground an academic subject that can easily be taught in an overly abstract manner. By the end of the course, it was clear that these students had reached a far higher level of understanding of knowledge mapping and were able to use the Cmap affordances to develop and convey complex ideas in a cognitively and aesthetically accessible form.

Classical instructional design models are generally represented by various kinds of flowcharts depicting each element in the design process as a node and the nature and flow of design between them as links. As the course progresses, some of the design elements may be made of smaller iterative or recursive elements. The flow of learning through a designed unit of instruction will also pass through assessment nodes in which decisions are made to branch the student on to the next topic, back for a review, or to an alternate instructional activity. Concept mapping, Cmap in particular, can easily represent all of these ideas and flows in a highly visual, informative, easily communicated, and easily revised system.

For example, in the first class, a simplified model of instructional design, called the ADDIE model, is presented. ADDIE stands for the instructional design steps of Analyze, Design, Develop, Implement, and Evaluate (Moldenda, 2008) and is represented in a circular graph suggesting that instructional design is a fundamentally iterative process that keeps feeding back on itself to improve. Cmap was used to progressively construct the model as one would draw the model on a chalkboard. The model was then saved to a Cmap server for convenient student access. The first student assignment was to use Cmap to visually apply the ADDIE model to an instructional task they knew well. Students were to save their Cmap assignments into *their* folder inside of the *course* folder on a public Cmap server. Within one week, all students had accomplished this many-stepped task and could access and review the instructor's materials and the work of the other students (to prepare them for collaborative assignments).

In the second class, Cmap was used to progressively construct the Dick & Carey model of instructional design (Dick, Carey, & Carey, 2005) that uses extensive branching and back propagation to represent iterative tasks. Color was introduced as a way to group design elements in a functional manner to better communicate meaning to a viewer, client, or audience. By the end of the second week, all students had integrated node color and font attributes as functional organizers and effectively used branching, directional arrows, and solid and dashed lines to communicate the flow of the design process. In a later class, Gagné's nine events of instruction (Gagné, 1985) and the breakdown of learning tasks into subtasks was taught and practiced in the same manner.

In subsequent classes, one or two Cmap affordances were demonstrated and required as part of the week's assignment. In this way, students built a knowledge map cognitive toolbox that included hot links to external resources, image integration, linked submaps, concealed/expanded nodes, mouse-over information, collaborative development, and presentation aesthetics. As classes progressed, students inspired one another with the creative ways they had constructed each assignment. By the end of the course, each student had a top-level concept map with a node that linked to each week's assignment as a sub-map, all publicly accessible from a Cmap server.

The students' final projects demonstrated that they had reached two important milestones in knowledge mapping. The first was that they could cognitively construct and then effectively represent and communicate the flow and relationships in any relevant domain. The second was that they could comfortably and easily use the Cmap system as a vehicle to develop, revise, and share their knowledge map with an arbitrary level of hidden, yet easily accessible complexity (see Fig. 6.2).

Each student selected a high-level, authentic project for her final project. Most projects were an instructional design to meet a defined need, but the Cmap system and the instructional design process were effectively used to support a wide variety of projects. For example, one student's final project was to support her application to a federal agency to fund her doctoral study. Another student's project was to map out the process for the reorganization of the development office at the college in which she is a program administrator. A foreign student used her personal experience to design an improved flow of activities that introduced, integrated, and supported new foreign students into the university environment. Several students stated they will continue to use Cmap and knowledge mapping as a way to organize, plan, and present ideas. They recognized that the instructional design process supported by tools like Cmap translates smoothly to the design of face-to-face or online courses not only for education but also for corporate, healthcare, and military instruction. Such an intensive graduate course experience, however, must be regarded as a luxury. The last case study explores the opposite of deep engagement with the question of how well concept mapping or Cmap can be introduced through the classic one-shot training workshop.

5 Case Study 4: Introducing K-12 Teachers to Cmap

Many K-12 teachers are familiar with commercial concept mapping software like Inspiration/Kidspiration, with free Web-based services like Bubble.us, or with one of the many iPad apps like Popplet. Teachers use all of these systems because each offers a low barrier to entry. But, while each is simple to learn, they offer few affordances to represent complex relationships or to collaborate with others. The drawing application in Google Docs is also used in classrooms to create concept maps. Google Docs supports collaborative editing, but the drawing system is just a picture of nodes and connectors without embodying the underlying relationship links that are the heart of a concept map. None of the commonly used systems seem to provide the affordances to support complexity and collaboration to the degree of the Cmap system. For that reason, the author has featured Cmap in presentations and workshops for nearly 1,000 K-12 teachers. Teachers typically chose these workshops based on their interest in the advertised topic. Therefore, most participants attended because they were interested in the topic and not because they were forced to attend a session they did not care about.

These presentations generally were 3-hour hands-on workshops advertised either as "the best of free classroom software" or as technology to "more deeply engage your students." The workshops typically devoted about 20-min to Cmap for a 5-min introduction, guided instructions to download and install the system, a guided 10-min experience to create a simple concept map, and a 5-min summary that demonstrated two advanced Cmap features. The advanced features, automated Web publishing, and collaborative editing were intended to show teachers desirable affordances that their current concept mapping systems did not provide. It is well known that one-shot workshops tend to have minimal effects in changing teacher behavior, but it was hoped that interested teachers would try out some of the software and techniques they had experienced. In general, their reaction was disappointing.

The idea of concept mapping was not new to most of these participants, although they tended to regard a concept map as a graphic, colorful, somewhat unruly kind of outline. Their two most common comments were that they already used Inspiration/Kidspiration and were happy with it and that they wish that a Cmap concept map could be output as a linear outline to serve as a framework for linear, written narrative. Their comments suggested two unstated, but important, teacher assumptions:

- Teachers seemed to assume that technology-supported activities would be encapsulated within the classroom and not be extended to the home or community. Teachers seemed unimpressed that students could freely load Cmap software on their home computers to empower independent skill growth. They seemed unimpressed that students could freely save Cmaps to no-cost servers as a way to seamlessly extend school technology activities to home and back. Teachers did not seem to value the automated conversion of concept maps to universally accessible Web pages complete with active links. Finally, they did not seem to value the ability of student online collaboration on Cmap development or revision within or outside of school such as among student home computers in the evening or weekend. These observations suggest that teachers may regard educational technology mostly as a teacher-directed, in-school activity. While there may have been some justification for this view before most families had computers, it has been the case for several years that nearly all children have access to an Internet-connected computer at home, at a friend's or relative's home, or at a public library.
- The second assumption goes deeper to the nature of knowledge and learning. Knowledge is structured more through the relationships among its variables than through definitions of facts and concepts. Deep learning can be evaluated by the degree to which a student can creatively apply her knowledge. In contrast to these ideas of knowledge and learning, US classrooms are now driven by the need to make *acceptable yearly progress* as measured by standards-based, high-stakes, generally multiple-choice tests. This trend was foreseen by academic standards advocates Tucker and Codding (2002, p. 21). "Some will use the new standards to narrow the curriculum into a little cleft in the rock of drill and practice in computation and grammar, as if this is all there is to a good education." The need that teachers stated to have concept map software generate a linear outline to be used for a linear narrative suggests that teachers are too focused, sometimes by restrictive policies or curricula, on teaching only what can be measured on a multiple-choice or writing composition test. Concepts such as *hyperlinking* or hot linking of one topic to another or to a resource is how the Internet works, yet the hot linking affordance in Cmap appeared uninteresting to most teachers. The larger concern is how our teachers and students can gain the cognitive tools, such as knowledge mapping, that they will need to navigate a rapidly expanding world of three-dimensional knowledge.

6 Conclusions

Cmap concept mapping software is a strong model of software with a “low floor” and “high ceiling.” There are minimal barriers to entry for faculty or students to begin the use of Cmap and other concept mapping systems to organize their ideas. Effective and independent use seems to require at least three scaffolded experiences so that new users can both learn useful affordances as well as better synchronize their concepts of learning and knowledge structure with that of the concept map system.

The observations from the four informal case studies are not surprising; greater experience with a topic yields greater depth of understanding. To summarize the case study observations:

- Most teachers in K-12 and higher education do not use knowledge mapping concepts or tools to help students learn content relationships or to help them map their own connections as they make them.
- There are obstacles of attitudes, assumptions, and priorities to wider K-12 adoption of powerful concept mapping systems and ideas that go beyond a paper map and the generation of a linear outline to help organize a linear narrative.
- Free concept mapping systems such as Cmap exist that can empower students or adults in their education endeavors, but the systems that train teachers and students tend to teach neither knowledge mapping ideas nor computer-based systems that can powerfully implement them.
- Short-term exposure of concept mapping or mapping tools through a 3-hour class or a 3-hour workshop can serve as a low-level awareness activity at best.
- Teachers may learn basic concept map ideas and operations through three or more hands-on activities in which they creatively apply the ideas and tools. This could be accomplished with a half-day dedicated to concept mapping followed by ongoing support or coaching.
- Deeper learning of knowledge mapping ideas and skills with tools like Cmap is needed before teachers and students can creatively and flexibly apply mapping ideas and systems. One effective way to do this is to use knowledge mapping and a powerful system like Cmap to build a connected cognitive map of content as a course progresses. Through a course-length integration of learning through concept maps, students build the mental models they need to begin to put knowledge mapping to use to meet their own needs. This approach would work for any subject and for students in any grade from fifth grade to adult. Tools like Cmap require scaffolded experiences, such as in Case Study Three described above, for students to learn the skills to know and use the powerful affordances that provide tools for them to think with and convey that thought to others.

The future of knowledge mapping tools may be a concern because of the rapid movement of the computer market from desktops/laptops to mobile devices like iPads and Android tablets. The desktop/laptop computer system runs complex applications that can easily work together and link to disparate resources. Tablet computers like the iPad and Android tablets don't run desktop/laptop software. They don't run cross-platform technologies like Java and Flash. Instead, it is expected that HTML5 and Javascript/CSS will provide a robust platform for interactive, media-rich apps. However, a complex system like CmapTools would need to be fully reprogrammed to run on iOS and Android devices. The Cmap Website currently states that they have neither plans nor funding to perform such a rewrite. Other simplified tools like Bubble.us and Google Docs don't begin to fill this gap. The question looms regarding what powerful and low-cost knowledge mapping tools will be available for teachers, students, and knowledge researchers as our school technology morphs from a computer-based model to the tablet-based model.

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Part II
Digital Knowledge Maps in Collaborative Learning Contexts

Chapter 7
Collaborative Work with Digital Knowledge Maps on Improving ESL Learners' Reading Skills

Pei-Lin Liu

Abstract Many researchers in education recognize that knowledge is socially constructed in collaborative groups. However, there are two problems in collaborative learning for English as Second Language (ESL) learners. First, when learners discuss one text without representing their ideas visually, it is difficult to communicate or share their ideas with each other. Second, when learners work collaboratively, it is hard to determine each learner's existing knowledge and contribution to a group. The strategy of collaborative knowledge mapping can solve problems previously stated by visually documenting each learner's contribution to the group's comprehension effort. One of the most important issues raised in this paper is whether collaborative groups should be heterogeneous or homogeneous to achieve maximum learning outcomes. This study examined a variety of grouping in first year English as a Second language (ESL) students ($N = 100$) enrolled in a Bachelor of Chinese Literature Degree at a university in Taiwan. Participants were randomly assigned to heterogeneous-pair or homogeneous-pair groups, and students worked in pairs to complete digital knowledge mapping assignments. All participants handed in their individual map as the first assignment, and the second group mapping assignment was the one according to different grouping conditions. The results indicated that the higher-level learners made more contribution when they were within heterogeneous-pair groupings, while the lower-level learners made more contribution when they were with the homogenous-pair grouping during the map creating process.

Keywords Ability grouping • Collaborative learning • Digital knowledge maps • Reading skills

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1 Introduction

Collaborative learning means that learners share their knowledge and solve the problems together (Haugwitz, Nesbit, & Sandmann, 2011). Some research shows that collaborative activities can enhance learners' knowledge construction and promote learners' intrinsic motivation more effectively than independent processes (Fischer, Bruhn, Grasel, & Mandl, 2002; Kwon & Cifuentes, 2009). The advantage of collaborative learning includes heightening self-esteem, creating caring and altruistic relationships, and lowering anxiety and prejudice (Oxford, 1997). Moreover, face-to-face interactions with peers enable students to reflect upon different past experiences and thoughts (Hwang et al., 2011). Therefore, collaboration becomes one of the major activity modes in today's education (Gao, Shen, Losh, & Turner, 2007).

Teachers in classrooms are finding ways to engage students in collaborative learning activities when teaching reading. There are two categories in collaborative learning; one is heterogeneous grouping, and the other is homogeneous grouping. Heterogeneous or mixed ability grouping is when students with different ability levels are grouped together. Homogeneous or ability grouping refers to the process of teaching students in groups that are stratified by achievement, skill, or ability levels (Mulcahy, 2012). The issue of grouping in reading instruction is crucial to educators and educational researchers (Kim, 2012). Brabham and Villaume (2001, p. 263) commented, "Sometimes we create groups of students who are reading on similar instruction levels; sometimes we form groups of students who will benefit from a particular strategy focus; and sometimes we group students heterogeneously to provide extended opportunities for sharing similar interests, collaborating, and peer modeling."

In the professional literature, heterogeneous groupings are advocated; while practitioners, however, most often advocate homogeneous groupings. Researchers and educators have struggled for years to find answers to the questions about ability grouping for collaborative learning activities (Petrello, 2000).

There are two other problems in collaborative reading, especially when learning English as a Second Language (EL). First, when learners discuss one text without representing their ideas visually, it is difficult to communicate or share their ideas with each other. Second, when learners work collaboratively, it is hard to determine each learner's existing knowledge and contribution to a group. During group discussion, some learners do not participate well and wait for the answers (Nussbauma et al., 2009). Other learners who do most of the work may learn more than more passive group members (AbuSeileek, 2012; Blumenfeld, 1992; Gayford, 1992; Ormrod, 1999; Webb, 2010). Instructors are not sure who has made more contributions and working quality in collaborative reading activities.

The strategy of collaborative knowledge mapping can solve problems previously stated by visually documenting each learner's contribution to the group's comprehension effort. The map can serve as a platform to record how learners interact, communicate, and exchange their opinions during map construction. Knowledge maps are a two-dimensional, hierarchical, and node-link diagram that represent verbal, conceptual, or declarative knowledge in a visual form (Novak & Gowin, 1984; Quinn, Mintzes, & Laws, 2003). Since knowledge maps can help learners to explicitly and visually represent their existing understanding, the maps can achieve the communication function. While learners discuss in collaborative groups they can use graphical representations to help negotiate meaning in the discussion. It therefore makes learning or communicating ideas a more active rather than a passive process (Campbell et al., 2006).

Knowledge maps can also facilitate the creation of shared understanding and reduce misunderstanding between individuals (Liu, 2010). Moreover, when learners collaboratively communicating using knowledge maps, the instructor can assign each individual different color to represent his/her contributions while the map-drawing process. In this way, the instructor can find out each learner's contribution and their exist knowledge easily through viewing the learners co-creating knowledge maps with different colors.

Digital knowledge mapping makes the learning process more accessible to students, and it reduced the frustration felt by students when constructing and revising knowledge maps by using computer (Anderson-Inman & Ditson, 1999; Know & Cifuentes, 2009). Traditionally, knowledge mapping was carried out using paper and pencil, but this usually created two problems. First, learners need to spend lots of time and effort revising their knowledge maps instead of concentrating on the reading content (Chiu, Huang, & Chang, 2000; Horton et al., 1993). Second, learners experience more frustration and feel exhausted because it is not convenient to construct and revise their knowledge map by using paper and pencil (Anderson-Inman & Ditson, 1999; Know & Cifuentes, 2009). Comparing with digital knowledge mapping, the use of traditional methods is less effective.

However, students might be frustrated at the beginning because they need time to know how to construct a map on the computer and the software might cost money for the students. Fortunately, more and more corporation began to develop free and user-friendly knowledge mapping products for brainstorming, thinking and organizing ideas. This study tries to investigate which grouping treatment can have the most benefits for different level ESL learners when creating digital knowledge maps. One of the most important issues raised in this paper is whether collaborative groups should be heterogeneous or homogeneous.

2 Literature Review

2.1 Research on Grouping in Collaborative Learning

Collaborative learning is a powerful technique that has been shown to increase student achievement and motivation (Baer, 2003). For heterogeneous grouping, some research indicates that learners may benefit more because higher-level learners can sharpen their understanding of class material by explaining it to their group members and lower-level learners can learn more by listening to others' explanations (Fuchs et al., 1997; Lou et al., 1996; Ormrod, 1999; Stevens & Slavin, 1995; Webb & Palincsar, 1996). However, other research shows that learners may not make great progress or even lose ground in the heterogeneous groups because higher-level learners cannot gain more knowledge from working with their lower-level learners and lower-level learners may only wait for the answers of others without thinking and discussing themselves (Lou et al., 1996; Ormrod, 1999; Tudge, 1990).

Very few studies have compared the effects of different methods of grouping students when collaborative learning has been used on different level learners. Higher-level learners in homogeneous groups can learn at their own pace without waiting for lower-level learners and they can move forward rapidly and have more challenge (Faris, 2009). Lower-level learners may be able to learn more when placed in heterogeneous groups, when placed in homogeneous groups they may lack the knowledge needed to provide crucial types of mutual assistance (Dillenbourg, Baker, Blaye, & O'Malley, 1996; Haugwitz et al., 2011; Lou et al., 1996).

2.2 Collaborative Learning with Digital Knowledge Map Approach

Many educational researchers (i.e., AbuSeileek, 2012; Baer, 2003; Faris, 2009; Stevens & Slavin, 1995) have recognized that knowledge is socially constructed in collaborative groups but it requires that each individual in the group must contribute to the group's overall success.

In using the knowledge mapping teaching approach, students organize concepts and relationships between them in a hierarchical manner from more inclusive concepts to the less inclusive ones. Digital knowledge maps fit well with a constructivist approach in that learners construct their own idiosyncratic understanding of concepts (Liu, 2010). Digital knowledge maps can be used by students to communicate with each other about what they know, therefore, can be integrated into collaborative learning activities and used as tools for socially negotiating meaning (Anderson-Inman & Ditson, 1999). The collaborative digital knowledge mapping approach brings together collaborative learning and digital knowledge mapping in. This is likely to motivate students by offering the benefits of both digital knowledge mapping and collaboration learning (Keraro, Wachanga, & Orora, 2007).

Collaborative digital knowledge mapping can serve as a learning opportunity for learners and instructors to interact, communicate, and exchange their opinions (Ruiz-Primo & Shavelson, 1996). In the process of collaborative knowledge mapping, it aids learners in learning the regularity of language usage and in strengthening their thinking ability through interaction, generalizing the text, and displaying key phrases in an orderly manner (Liu, 2010).

Most of the research on the effects of digital collaborative knowledge map has investigated its influence on learners' achievement and motivation (i.e., Hwang et al., 2010; Keraro et al., 2007; Lin, 2011; Liu, Chen, Li, & Shen, 2011). The process of group negotiation allows for a shift from internal negotiation for students, and it also results in meaningful integration of new concepts in the cognitive structures of learners (Kwon & Cifuentes, 2009). However, there is little research available on its effectiveness among different level learners' comparison.

Liu (2011) conducted one study using digital knowledge mapping on English writing skills. The result indicated that the high-level learners performed significantly better in the individual-mapping treatment than in the collaborative-mapping treatment. The low-level and middle-level learners in this study performed better when receiving the collaborative knowledge mapping treatment than the individual mapping treatment. Under the heterogeneous collaborative setting, the lower- and middle-level learners got writing assistance from the higher-level learners to improve the quality of their writing compositions. On the contrary, while receiving the heterogeneous collaborative mapping treatment, the higher-level learners spent most of their time helping other level learners by switching roles as map concept organization editors, map readers, and map constructing consultants. Heterogeneous grouping method increased the higher-level learners' workload during the map-drawing process and reduced their own writing time in the limited class period.

3 Methodology

3.1 Experimental Design

The researcher used quasi-experimental design in this study. Participants were randomly assigned to two groups, and both groups completed a digital knowledge mapping assignment. The difference among the groups was the grouping methods, which are including: heterogeneous-pair grouping ($N=50$), and homogeneous-pair grouping ($N=50$). The students worked in pairs to co-created knowledge maps. All participants handed in their individual map as the first assignment, and the second assignment was the one according to different grouping conditions. As a result, the participants in heterogeneous-pair grouping and homogeneous-pair grouping handed in one individual and one collaborative mapping assignment (see Table 7.1).

Table 7.1 Description of quasi-experimental design

	Mapping assignments	
Treatment groups	First	Second
Heterogeneous-pair	Individual	Collaborative
Homogeneous-pair	Individual	Collaborative

Table 7.2 Description of pair grouping methods

Treatment group	Participants		Group number
Heterogeneous-pair	Higher-level	$N=25$	25
	Lower-level	$N=25$	
Homogeneous-pair	Higher-level	$N=25$	25
	Lower-level	$N=25$	
	Total	100	50

3.2 Participants

The study involved 100 first year students of English as a Second Language in a Bachelor of Chinese Literature Degree in one university in Taiwan. The participants were divided into two groups: heterogeneous-pair group ($N=50$), and homogeneous-pair group ($N=50$). The average length of time they had spent learning English was at least 6 years, from middle school to high school. Before the class, learners were able to read stories and short articles.

For knowing the impact of different grouping treatments on the map quality, the researcher further divided the participants into lower-level and higher-level learners according to the result of participants' pre-reading test. As a result, there were 25 lower-level learners and 25 higher-level learners in heterogeneous-pair group. There were 25 lower-level learners and 25 higher-level learners in homogeneous-pair group (see Table 7.2).

3.3 Instruments

3.3.1 Reading Material

Articles included in the high-intermediate proficiency level of Studio Classroom English magazine were selected as the reading materials in this research. The researcher chose three articles from this magazine for the map-drawing activities: "Snoopy's Big Day?" (Hagerla, 2010), "United the commonwealth through sport" (Ewald, 2010a), and "Top ten teacher tips" (Ewald 2010b). The basic vocabulary size required for the readers was 3,000–5,000 words. The magazine was chosen as the teaching material not only in consideration of the articles being novel and lively, but also because they are graded to different English proficiency levels. It was not necessary for the learners to have any pre-knowledge of any specific domain before they could understand the articles.

3.3.2 Post-reading Tests

The purpose of the pre- and post-tests was to evaluate the subjects' English ability before and after they read the articles. There were 25 reading comprehension test items for each test. Participants whose pre-test scores were higher than the average scores were regarded as higher-level learners. However, those whose scores were lower than the average were regarded as lower-level learners. Four types of questions included in the two post-reading tests were: (1) factual questions, (2) inference questions, (3) main idea questions, and (4) tone questions. Factual questions are empirical questions how/why things occur? Unlike factual questions, inference questions do not test learners' knowledge of explicitly cited facts, but rather their ability to draw conclusions from other information. Main idea questions ask the test taker to identify the passage's overall theme, as opposed to supporting facts and arguments. Tone questions usually ask what the author's tone is, but may occasionally ask for the author's attitude (Chen & Liu, 2012).

3.3.3 Concept Mapping Scoring System

For the concept maps that the participants handed in, the author adopted the scoring system of Novak and Gowin (1984), classified scoring according to the topics assigned (one point for a meaningful assigned topic), hierarchical level (five points for a valid hierarchy), cross-link (ten points for every valid cross-link), and examples (one point for every example). The highest possible score for every map was 100. The scoring for the concept maps was completed by an outside independent scorer.

3.3.4 Concept Mapping Software Program

Inspiration is a user-friendly software that combines diagrams and outlines together to form a concept map (www.inspiration.com). Featuring visual learning and thinking software tools, Inspiration is most widely known for its use in building graphic organizers, such as concept maps, diagrams, and webs.

The corporation of Inspiration Software was founded in 1982 by Helfgott and Westhaver, and was originally focused on business software products. In 1987, the corporation began to develop products for brainstorming, thinking and organizing ideas. In 1996, the software package Inspiration was released (Liu, chen, & chang, 2010). It utilizes research principles and strategies to meet the needs of educators and students, and it is also the advantage of this software over others.

English language learners that use this software can create their concept map on the window of the software. Liu utilized it to assist learners to structure their work for EFL English reading (2010) and writing (2011). Learners learn how to explore and explain relationships among reading concepts. While planning writing, learners also learn how to brainstorm and create essay outlines to support the writing process by this package. The results indicated learners organize ideas and think through reading or writing projects more effectively using Inspiration.

Table 7.3 Description of procedure

Week 1	Participants took a pre-reading test
Week 2	Participants received digital knowledge mapping instructions
Week 3	Participants practiced drawing knowledge map by hand
Week 4	Participants read "Snoopy's big day?" as a practice for creating a knowledge map
Week 5	Participants created "United the commonwealth through sport" as individualized knowledge mapping assignment
Week 6	Participants undertook the first post-reading test
Week 7	Participants completed the collaborative knowledge maps of "Top ten teacher tips"
Week 8	Participants had their second reading test

3.4 Procedure

All participants took the pre-reading test in the first week of Semester 1/2010. The purpose of the pre-reading test was to evaluate the subjects' English reading ability before they accept the concept-mapping treatment.

From the second to the third week, all participants received digital knowledge mapping instructions, and practiced drawing knowledge map by hand. In the fourth week, all participants read one article to be used as a practice for creating a knowledge map. On week 5, all participants created "United the commonwealth through sport" as individualized knowledge mapping assignment. In the following week, all participants conducted the first reading test of "United the commonwealth through sport".

On week 7, the participants completed the collaborative knowledge maps of "Top ten teacher tips". In the last week, all participants had their second reading test. The scoring system was adopted form Novak and Gowin (1984) for the knowledge mapping assignments (Procedure is shown in Table 7.3).

4 Result

All participants took the pre-reading test prior to the experiment. In order to find out whether there was any significant difference between the two groups (heterogeneous-pair and homogeneous-pair groups) on participants' reading proficiency. The results show that the mean scores for the pre-reading test is 58.69 (SD = 11.01) for the heterogeneous-pair group and 59.81 (SD = 11.84) for the homogeneous-pair group. An independent *T*-test was then conducted, the participants of the two groups have the same reading proficiency before the experiment ($t = -0.38$, $p = 0.70$).

The students' English reading performance score for the two types of grouping are shown in Table 7.4. All participants received their first reading performance test after they finished conducting their individual knowledge map. The results indicate that there is no significant difference on their first post-reading test. However, there is significant difference on participants' second post-reading test performance.

Table 7.4 Descriptive independent *t*-tests statistics of first and second post-reading comprehension scores for two groups

Treatment Group	First post-reading test scores After individual mapping assign				Second post-reading test scores After collaborative mapping assign			
	M	SD	*t*	*p*	*M*	SD	*t*	*p*
Heterogeneous-pair	55.06	19.67	1.02	0.31	56.12	15.84	2.14	0.04*
Homogeneous-pair	59.08	19.61			63.65	56.12		

$^*p<0.05$

Table 7.5 Descriptive independent *t*-tests statistics of collaborative knowledge mapping score for two groups

	Treatment group	*M*	SD	*t*	*p*
Total Scores	Heterogeneous-pair	96.75	37.45	−0.49	0.62
	Homogeneous-pair	100.14	30.08		
Relationship	Heterogeneous-pair	24.96	8.93	−3.09	0.00*
	Homogeneous-pair	30.86	10.10		
Hierarchy	Heterogeneous-pair	22.94	7.62	−0.53	0.60
	Homogeneous-pair	23.78	8.26		
Cross-link	Heterogeneous-pair	24.71	26.56	−0.42	0.68
	Homogeneous-pair	26.73	22.21		
Example	Heterogeneous-pair	6.98	7.51	0.39	0.70
	Homogeneous-pair	6.47	5.20		

$^*p<0.05$

The research indicates that the participants in the homogenous-pair group performed better on their post-reading test than participants in the heterogeneous-pair group (Table 7.4).

The participants' second knowledge maps were analyzed to determine whether there was a difference in their mapping scores by two different grouping. In Table 7.5, it shows that though there is no significant difference on total scores between these two groups, the participants in homogeneous-pair group have conducted more mapping relationships when they are in the homogeneous-pair group than in the heterogeneous-pair group. Also, the mean of the maps which the participants in homogeneous-pair group conducted have better scores than those in heterogeneous-pair group.

In order to find out which kind of grouping for different level learners is more beneficial, *t*-test were carried out. Table 7.6 describes the performance for high-level learners in two groups, and there is no significant difference on their contribution scores. Thus, regardless whether higher-level learners where in heterogeneous-pair group or in homogeneous-pair group, they had similar contribution scores on their collaborative knowledge maps.

Table 7.7, describes the performance for lower-level learners in two groups, and there is a significant difference on their contribution scores ($p<0.05$). Therefore, lower-level learners have different knowledge mapping scores because of different grouping. Also, according to the mean, lower-level learners in homogeneous-pair group ($M=83.71$) have better scores than those in heterogeneous-pair group

Table 7.6 Descriptive independent *t*-test statistics of collaborative knowledge mapping score for higher-level learners in two groups

		M	SD	*t*	*p*
Contribution Score	Heterogeneous-pair	93.81	43.13	0.01	0.26
	Homogeneous-pair	93.69	28.79		
1. Relationship	Heterogeneous-pair	26.57	9.51	−2.12	0.44
	Homogeneous-pair	31.72	7.99		
2. Hierarchy	Heterogeneous-pair	25.71	9.12	0.88	0.09
	Homogeneous-pair	23.75	6.95		
3. Cross-link	Heterogeneous-pair	34.76	34.87	0.75	0.17
	Homogeneous-pair	28.44	25.91		
4. Example	Heterogeneous-pair	6.76	5.95	−0.89	0.13
	Homogeneous-pair	8.47	7.27		

Table 7.7 Descriptive independent *t*-test statistics of collaborative knowledge mapping score for lower-level learners in two groups

		M	SD	*t*	*p*
Contribution score	Heterogeneous-pair	66.90	22.24	−2.20	0.03*
	Homogeneous-pair	83.71	26.38		
1. Relationship	Heterogeneous-pair	24.21	8.38	−1.57	0.12
	Homogeneous-pair	29.24	13.35		
2. Hierarchy	Heterogeneous-pair	21.03	5.88	−1.15	0.25
	Homogeneous-pair	23.82	10.53		
3. Cross-link	Heterogeneous-pair	17.93	16.12	−1.22	0.23
	Homogeneous-pair	23.53	12.71		
4. Example	Heterogeneous-pair	5.07	4.91	−1.03	0.31
	Homogeneous-pair	7.00	7.76		

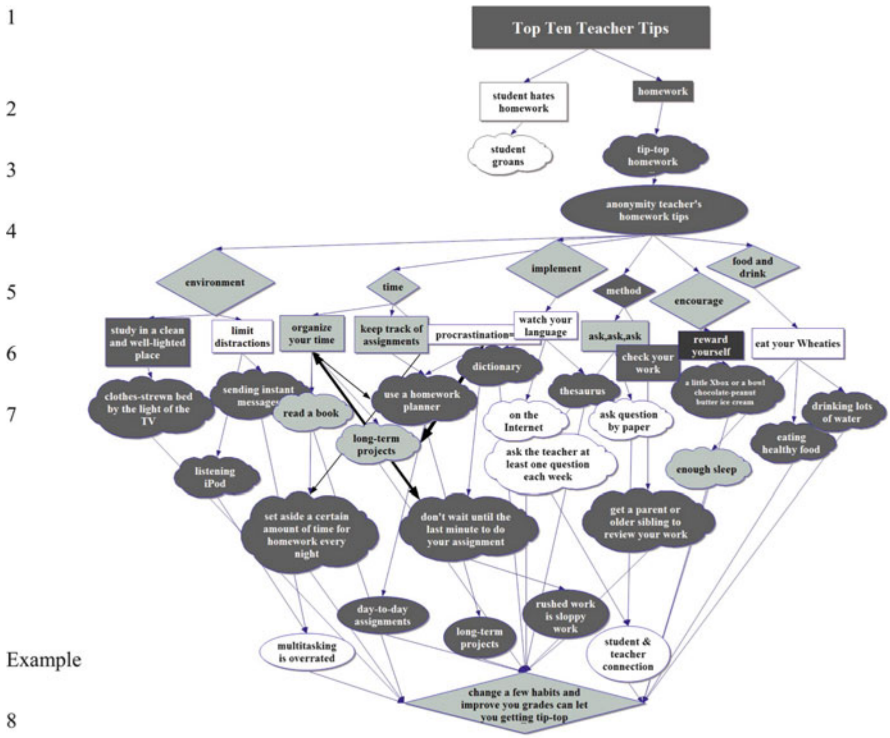
*$p < 0.05$

($M = 66.90$). It shows that lower-level learners in homogeneous-pair group constructed more knowledge mapping elements than they have in the heterogeneous-pair group (see Figs. 7.1, 7.2 and 7.3).

5 Discussion and Conclusion

The aim of this study was to find out the best grouping for different level ESL learners on their English reading ability and the scores of their knowledge mapping. These results suggest that when using collaborative learning, homogeneous grouping results in higher achievement than heterogeneous grouping.

The study also explains why homogeneously grouped students outperformed heterogeneously grouped student in constructing knowledge maps. The result revealed that the participants in homogeneous-pair group created more knowledge mapping relationships than the heterogeneous-pair treatment. The higher ability students had similar scores under two different grouping treatments. However, the lower-level

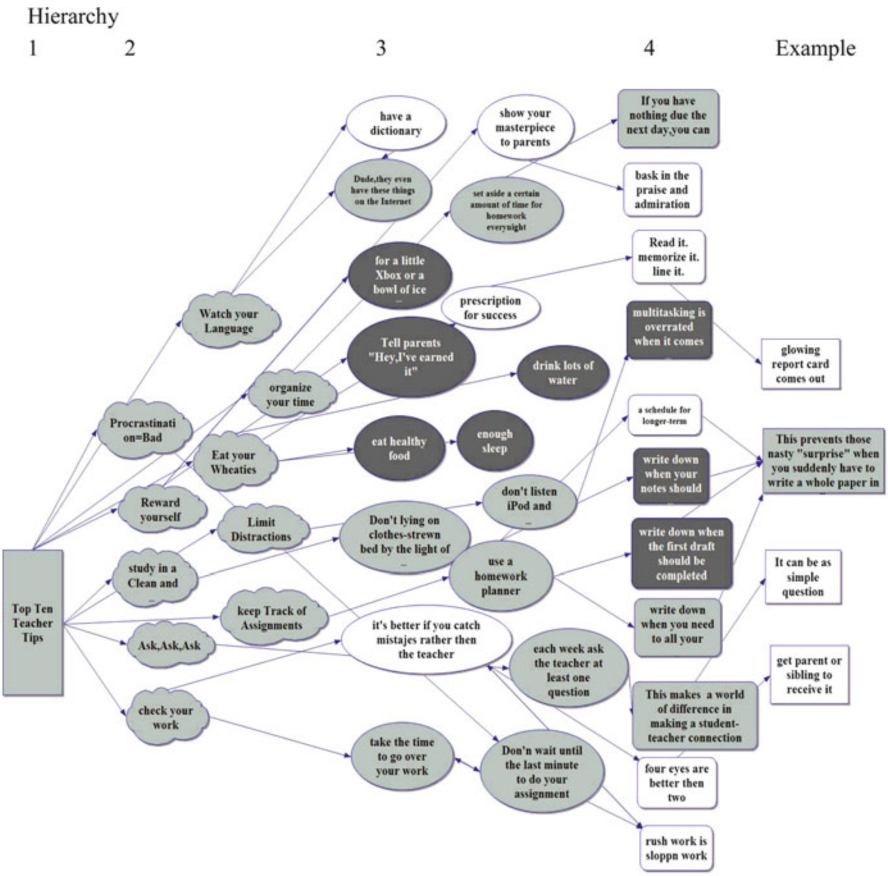


	Higher-level (dark gray)	Lower-level (white)
1.Relationship	= 17*1 point+12 (light gray)	= 8*1 point + 12 (light gray)
2.Hierarchy	= 8*5 point	= 6*5 point
3.Cross link	= 3*10 point	= 2*10 point
4.Example	= 3*1 point	= 2*1 point
Contribution Score	= 112	= 45

Fig. 7.1 Knowledge map developed by students in the heterogeneous-pair group and scoring. *Note*: If different level students came up with similar ideas, it indicated with *light gray color*

learners in homogeneous-pair groups had more contributions on their collaborative knowledge maps. One possible explanation is that slower achievers may feel inferior as compared to those achieving at a higher level when being assigned as heterogeneous grouping (Pacheco, 2011; Scaife, 2011). Lower-level learners in homogeneous-pair groups may have more confidence and may like to create more and learn more (Chu, Lee, & Tsai, 2011; Zohar, Degani, & Vaaknin, 2001).

Under the homogeneous collaborative setting, the lower-level learners received assistance from peers with similar ability to improve the map quality (i.e., relationship, hierarchy, cross-link, and example). Moreover, the learners may have felt free to communicate with each other before, during, and after the map-drawing process to facilitate the creation of shared understanding (Fraser, 1993). During the process

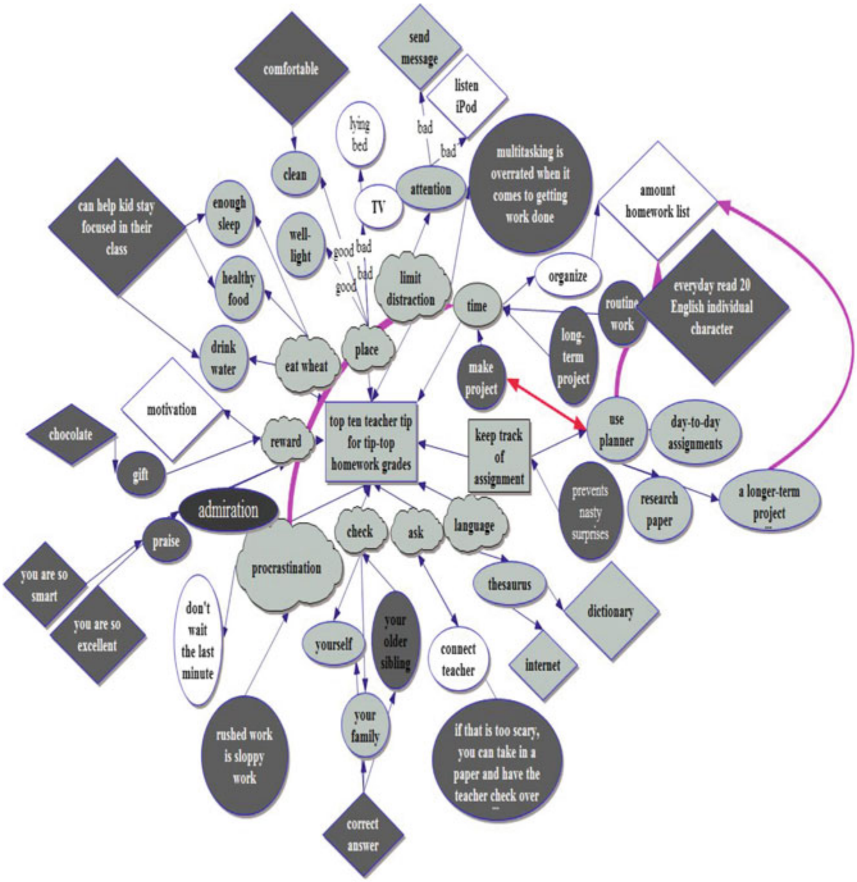


	A Lower-level (dark gray)	B Lower-level (White)
1.Relationship	= 8*1 point +23 (light gray)	= 11*1 point + 23 (light gray)
2.Hierarchy	= 4*5 point	= 4*5 point
3.Cross link	= 1*10 point	= 1*10 point
4.Example	= 0*1 point+1 (light gray)	= 3*1 point+1 (light gray)
Contribution Score	= 62	= 68

Fig. 7.2 Knowledge map developed by students in the lower-level homogeneous-pair group and scoring. *Note*: If different level students came up with similar ideas, it indicated with *light gray color*

of collaboratively developing knowledge maps using visualization tools, most lower-level learners are passive learners. The role of the student should evolve from being a passive learner to becoming an active participant in the learning process as the student's perceptions and representation of those perceptions are challenged, and learning builds on what the learner has already constructed in other contexts.

For higher-level learners, because their high linguistic competence might have enabled they to use oral or written text only to communicate with others (Ariew &



	A Higher-level (dark gray)	B Higher-level (white)
1.Relationship	= 18*1 point +27 (light gray)	= 8*1 point + 27 (light gray)
2.Hierarchy	= 5*5 point	= 5*5 point
3.Cross link	= 3*10 point	= 3*10 point
4.Example	= 8*1 point+1 (light gray)	= 10*1 point+1 (light gray)
Contribution Score	= 109	= 101

Fig. 7.3 Knowledge map developed by students in the higher-level homogeneous-pair group and scoring. *Note*: If different level students came up with similar ideas, it indicated with *light gray color*. *Note*: The *three bold arrows* used for indicating the cross-link between concepts

Ercetin, 2004), the performance did not significantly difference between two grouping treatment.

To sum up, the instructors could consider learners' differences and their mapping treatment preferences when assigning writing tasks. With the assistance of collaborative-mapping, learners could generate and organize their ideas during the reading process, and then use the map as a reference to organize the framework while putting content coherently into different map parts. It is worth noting that the higher-level learners in this study made more contributions when they were with the heterogeneous grouping, while the lower-level learners made more contribution when they were with the homogenous grouping during the map-drawing process. By considering learners reading performance, the authors suggest that further research may choose homogeneous collaborative-mapping treatment rather than heterogeneous treatment in order to maintain higher-level learners' performance and increase lower-level learners' participation in the map-drawing process.

This study is limited in several areas that should be investigated in future studies. First, while participants creating collaborative knowledge maps as group work, it was really hard to share one computer or work together on the screen simultaneously. The multi-touch screen of computers can allow more than one learner to draw maps at the same time and may reduce learners' frustration. Besides downloading the software to personal computers, the further researchers may apply the software to other mobile devices with multi-touch screen such as laptops, personal digital assistants (PDAs), and mobile phones for extending the power as ubiquitous learning to learners. It enables learners to organize content more efficiently while sharing one screen to do group work. Moreover, the further researcher may increase the group size from two to more learners after solving the screen sharing difficulty. The student then can work in small group of three to four people instead of working in pairs.

On the other hand, the reading test and map scores were collected to explore the effects of using different grouping treatments quantitatively. The content analysis of collaborative behaviors and interaction among peers are suggested to discover heterogeneous/homogeneous group mapping behaviors for future examination. These quality data might be helpful for researchers to understand student working process through the analysis.

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Chapter 8
Researching Individual and Collaborative Pair Learning in Primary School Students Using Digital Knowledge Maps for Science Education

Andreanna K. Koufou, Marida I. Ergazaki, Vassilis I. Komis, and Vassiliki P. Zogza

Abstract Researching conceptual understanding and development in learning requires recording and evaluating students' knowledge structures, either collaboratively or individually formed, but also requires investigating equally the learning process as well as the learning outcomes. The dynamic nature of knowledge maps, their potential as a life-long learning strategy, and their evaluation through a valid assessment protocol could serve those requirements. The following chapter records a case study in which 16 sixth grade students (10 years old) participated of a Greek state elementary school of an urban area, randomly selected. The students constructed and revised digital knowledge maps at various phases of a Science course both individually and in pairs. The research process involved collecting a succession of individually and collaboratively constructed knowledge maps. The series of knowledge maps was evaluated with a specifically designed protocol to assess multiple aspects of the knowledge structure process. The research aims at highlighting knowledge maps as a more sensitive assessment method of the learning process, compared to traditional tests and at underlining their effective use as a monitoring and assessment tool in collaborative environments. Results showed that graphics such concepts maps are more sensitive to subtle changes in student's understanding.

Keywords Individual learning • Collaborative learning • Learning process • Digital knowledge maps • Assessment protocol

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1 Introduction

Researching collaborative learning of students is a highly demanding task due to the necessity of recording closely and evaluating systematically students' knowledge structures, collaboratively formed, as members of a group, but also those that were individually formed. The nature of knowledge maps is dynamic provided they represent conceptual understandings and their development. They record knowledge structures of learning and, if obtained in regular intervals, they document the transition from one stage of knowledge to another. Thus, as learning strategy, knowledge mapping is more effective when it is carried out over a longer term. The study of a knowledge map's sequence which was constructed in various phases of the learning process is able to reveal a student's transition from preexisting knowledge structures to new ones (Carey, 1985; Novak & Musonda, 1991; Wallace & Mintzes, 1990). With this in mind, the knowledge maps may also constitutes a student's study tool for conceptual development (Pearsall, Skipper, & Mintzes, 1997). In other words, in the framework of constructivism, the learning process does not necessarily aims at adopting a scientific model, but at constructing new knowledge. For this reason, a method of study and evaluation of students' maps does not necessarily include the comparison with the educator's map or an expert's map. Alternatively, the comparison of knowledge maps of the same students as progressive snapshots during the knowledge construction process may be used. Thus, the researcher investigates equally the learning process as well as the learning outcomes (Iuli & Helldén, 2004; Novak & Musonda, 1991). This process can be simplified by the use of knowledge mapping software.

The following chapter records a case study in which a group of 16 students (aged 10 years) in the sixth grade of a Greek primary state school constructed and revised digital knowledge maps at various phases of a Science education course, both on their own and in pairs. The research process involved collecting sequences of individually and collaboratively constructed knowledge maps. It enabled assessing individual and collaborative knowledge structures in various phases of the Science education course and allowed comparative analysis. An assessment protocol designed by the researchers for that purpose was used to record possible interactions between members of the group. The research aims at highlighting knowledge maps as a more sensitive assessment method of the learning process, compared to any traditional tests applied after teaching process. Additionally it aims at underlining the effective use of knowledge maps as a monitoring and assessment tool in collaborative environments.

2 Theoretical Framework

Knowledge maps are a cognitive tool variously used in the learning process. They were first presented by Novak and Gowin (Novak, 1977, 1990, 1998; Novak & Gowin, 1984) and were based on the theories of Ausubel (1978). They are a popular way to represent knowledge (Fisher et al., 1990; McAleese, 1994; Novak & Gowin, 1984) and to reveal the representations of the person that takes part in the learning process (Fisher et al., 1990; Jonassen & Marra, 1994).

In a constructivist framework a person develops cognitive models that serve future thinking or acting. The process of knowledge construction depends on our conceptual representations. Effective learning means structuring new knowledge models by using, expanding, revising, or erasing the preexisting representations. Thus, the study of representations is a crucial matter in order to design appropriate educational environments. Therefore, the starting point of learning is what a person knows or ignores before teaching (Novak, 1977). Knowledge maps are able to record students' knowledge structures before teaching and also in the various phases of an instructional course. They measure aspects of learning which conventional tests do not measure sufficiently enough. For example, knowledge mapping can provide information about students' misconceptions and incorrect conceptions, which are usually unavailable in conventional tests (Heinze-Fry & Novak, 1990; Roth & Bowen, 1993).

Furthermore, traditional tests that are taking place after the completion of teaching instruction do not allow a complete view of how students construct knowledge during it. They often assume that group members have made equal contributions to the task and give the same grade or reward to each member, which is unfair and usually insubstantial.

Though learning is a dynamic and progressive process, monitoring it in a collaborative environment means first monitoring individual and collaborative learning and additionally monitoring them in various phases of the process. However, monitoring the learning process is a complicated and demanding activity. It often requires external support to keep track of what has happened and what is going on in the learning process (Wang et al., 2009). Information and Communication Technologies (ICT) tools can be used to monitor the learning process.

Finally, use of knowledge maps as an assessment tool even if this raises concerns about the scoring systems and associated validity and reliability, originated in qualitative characteristics but is generally considered a promising method. In order to be effective, a systematic, qualitative orientated, and simultaneously easy-to-apply procedure is needed.

There are many rubrics suggested in the literature on knowledge maps assessment, usually depended on how the map was generated (Turns, Atman, & Adams, 2000). If the user freely identifies concepts related to the subject, then assessment may be either structural or relational (West, Park, Pomeroy, & Sandoval, 2002). A structural, quantitative assessment assigns weighted scores to graph characteristics as number of concepts, links, cross-links hierarchical levels (Novak & Gowin, 1984). Relational, qualitative assessment is achieved by comparing the map to an expert-map, in order to evaluate more qualitative characteristics and score the overlap between them. This strategy assumes that there is some ideal organization that best reflects the structure in a domain (Ruiz-Primo & Shavelson, 1996).

Quantitative assessment can be objectively calculated but does not take under consideration the quality of concepts, links, and propositions. Qualitative assessment is considered to be more subjective. However, it may have an advantage over structural methods for complex maps due to the fact that it emphasizes on map correctness and overall quality. Both quantitative and qualitative assessments can reveal valuable information about understanding, as well as the ability to reveal changes in understanding over time (Edmondson, 2000; Kinchin, Hay, & Adams, 2000).

3 Methodology

The study aims at showcasing knowledge maps as a more sensitive assessment method of the learning process, compared to traditional tests and at demonstrating their effective use as a monitoring and assessment tool in collaborative environments. Thus, the objective of the study is to highlight:

- The use of knowledge maps as a way to simultaneously monitor individual and collaborative knowledge structures
- The use of knowledge maps as a way to monitor the learning process as well as the learning outcomes
- The advantages of knowledge maps as an assessment tool in comparison to traditional evaluation tests
- The use of knowledge maps as a tool to reveal conceptual representations and finally
- The advantages of computer supported knowledge mapping under real class conditions

The following paragraphs describe the study, which took place under real class conditions from October 2009 to March 2010. Sixteen 10-year-old students participated, and formed eight groups, with two members in each. Those pairs were created by evaluating the students' answers to questionnaires about the topic, setting as a criterion their common ideas about the subject of the curriculum, which was: "Energy and environment." Every student pair constructed and reconstructed individually but also collaboratively knowledge maps before and after various phases of instruction. For that, they used freely available knowledge mapping software named "Modelling Space," which was developed by the University of Patras in collaboration with the Aegean, Angers, Lisbon, Mons-Hainut, and Schlumberger Sema Universities (www.ecedu.upatras.gr). The chosen software was developed exclusively for educational use, is easily applied and the only one keeping log files. The research started with the study of conceptual representations as they appeared in knowledge maps structured by students before teaching, individually and in collaborative pairs. Then, a course was designed, taking into consideration these representations. During the course, the students, individually and in collaborative pairs, constructed, revised, or reconstructed their maps after various phases of the teaching process. The comparative analysis process of this sequence of knowledge maps follows:

- In order to study the individual's learning, the sequences of the individual maps constructed before and after every phase of the course for every member of the group were compared.

- In order to study the collaborative learning process and outcome, the collaborative maps constructed before and after every phase of the course for every pair were compared.
- In order to study the possible interactions between the two members of a group, the individual maps constructed before instruction and after every phase of the course with the correspondent collaborative maps were compared.
- In order to study the possible influence of the collaborative learning on the individual learning, every collaborative map and the individual maps which followed its construction were compared.

The assessment protocol used was developed by the researchers and evaluated the structure, the concepts and the propositions in quantitative and qualitative terms. In the following section this assessment protocol is presented in detail.

3.1 The Assessment Protocol

Traditional assessment tools but also knowledge maps used as an assessment tool are usually applied after teaching. Both offer information about students' knowledge and knowledge structure correspondently in a given time, after the teaching of a course. Thus, they are not able either to reveal what students knew before teaching (on which conceptual representations they did base their knowledge structure) or to give evidence about the structure process at the moment of the assessment before reaching its final form. Additionally, exclusive use of scoring rubrics underestimates qualitative characteristics of a concept map. A total score does not necessarily reveal the structural development (Baxter, Glaser, & Raghavan, 1993). But also relational assessment methods are applied only for the purpose of research as, they are time-consuming methods and cannot be adopted for that reasons under real class conditions.

On the other hand, a comparison between maps generated from the same student at various, crucial points of the learning process, based in the assessment protocol presented above, is an easily applied procedure by an instructor. It is believed that it could enlighten conceptual changes in the learning process of an individual.

The assessment protocol which was used to evaluate the knowledge maps contains four main criteria of analysis: structure analysis, concept analysis and propositions, links and labels analysis. These are defined as follows.

1. Structure analysis includes the structure type and the conceptual strategy analysis. In detail, the structure types presented below are considered appropriate for analyzing knowledge maps generated from students on science topics, taking into consideration previous research on similar topics Kinchin et al., 2000; Kinchin, 2001) and the basic structure types of knowledge maps, as they are described by Novak (1977). Conceptual development is revealed when passing from the first type (chain) towards the others (Anderson-Inman & Ditson, 1999):

- Chain, one concept leads to the other, revealing causality or succession
- Spokes, concepts are connected exclusively to the central concept and not with each other. This type of connection does not illustrate understanding of the relation between concepts, but only an understanding of the relation between the concepts and the central concept
- Tree, there is hierarchy but there are not cross-links between concepts
- Networks, there is hierarchy, multiple links, and cross-links between concepts

2. Conceptual strategy describes the way concepts are linked, revealing the conceptual or structural relations between concepts. There are five categories used in the present protocol:

   - Analysis, is defined as the passing from a general concept to its specific sub-concepts
   - Synthesis, is the linking of two or more sub-concepts to a general concept
   - Connection, a conceptual strategy is defined as "connection" when various concepts are linked to a new concept, which includes a common characteristic of the concepts linked to it and is of successive level
   - Enrichment, is defined as the addition of concepts, as it is described below, under the condition that it is not possible to take place in at the initial construction of a map, thus with concepts linked successively to the central concept. Enrichment includes two subcategories:

     – Adding extra pieces of knowledge. Addition of concepts-examples or concepts that add an extra parameter
     – Adding a process description. Addition of a sequence of concepts which describes a process

   - Listing pieces of knowledge. Listing pieces of knowledge strategy is defined as the linking of the central concept to one or more concepts, non-sub-concepts, which add pieces of knowledge related to the central concept

3. Concept analysis includes the quantitative and qualitative examination of a map, thus the number of concepts and the type, defined as theoretical and descriptive. It takes under consideration the following characteristics of a knowledge map:

   - Number of concepts. When the number of concepts included in a concept map increases, it is usually considered as a sign of conceptual development but this is not always the case. In order to reach a safe conclusion, the type of concepts has to be included
   - Type of concepts. Concepts are categorized in two types: school science concepts and everyday life concepts. School science concepts are defined as those which embrace scientific knowledge, emanating from school science.

On the other hand, everyday life concepts are defined as those which come from student's every day perception and are usually concept-examples
- Aspects of topic. Aspects of topic do not necessarily coincide with structural levels of a map. They are defined as dimensions of a topic, included to a course or curriculum and possibly contain more than one concept

4. Proposition, links, labels analysis. The way that two concepts are linked and the way that this link is labeled give evidence about the conceptual status of a student which is either valid or not (Kinchin, 2001; Kinchin et al., 2000). The links, labels, and proposition analysis includes the number of links, the type of links, defined as plain and cross-links, the type of labels, defined as word or phrase, the variety of the labels, defined as the fraction of labels (repeated labels are counted once) to links, under the condition that concept map includes sufficient number of links, depended on the topic. Finally, the validity of the propositions, defined as valid, nonvalid and of medium validity. Proposition of medium validity is considered a proposition that indicates an incomplete knowledge structure but it is a kind of transition to a complete one, as it is being revealed through the comparative analysis of knowledge maps. Moreover, a non-labeled link characterizes a proposition of medium validity.

In order to test the reliability of the rubric, we applied it in three different case studies. Indicative knowledge maps of the three case studies were assessed by the researcher and two more experts in order to conclude about the inter-rater reliability of the assessment protocol. The correlation results, as analyzed by the use of Oline Kappa Calculator (www.justus.randolph.name), are satisfying. The average percent of overall agreement is 0.807400, when the concept map presenting the worst percent of overall agreement is 0.644444 and the best one is 0.999999. Thus, taking also under consideration the fact that the knowledge maps come from three different case studies we are able to conclude that the protocol of concept map analysis is reliable.

4 Results

The research process described above involved collecting sequences of individually and collaboratively structured knowledge maps. Thus, the capability to assess individual and collaborative knowledge structures in various phases of the teaching course was given. Additionally, through comparative analysis based on the described assessment protocol interactions between members of the group were obtained. To illustrate this in a practical application, the comparative analysis of the sequence of individually and collaboratively structured knowledge maps by the group named "Energy" is presented (Table 8.1):

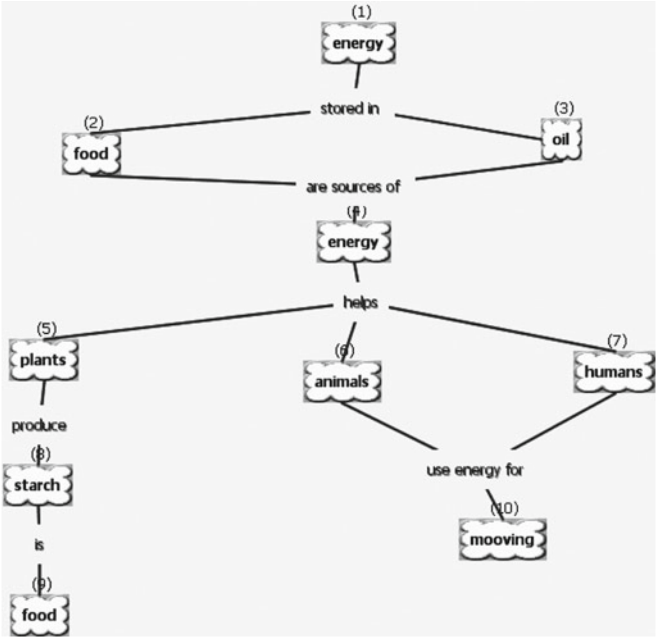

Fig. 8.1 Individual map, constructed before instruction, of the second member of the group "Energy"

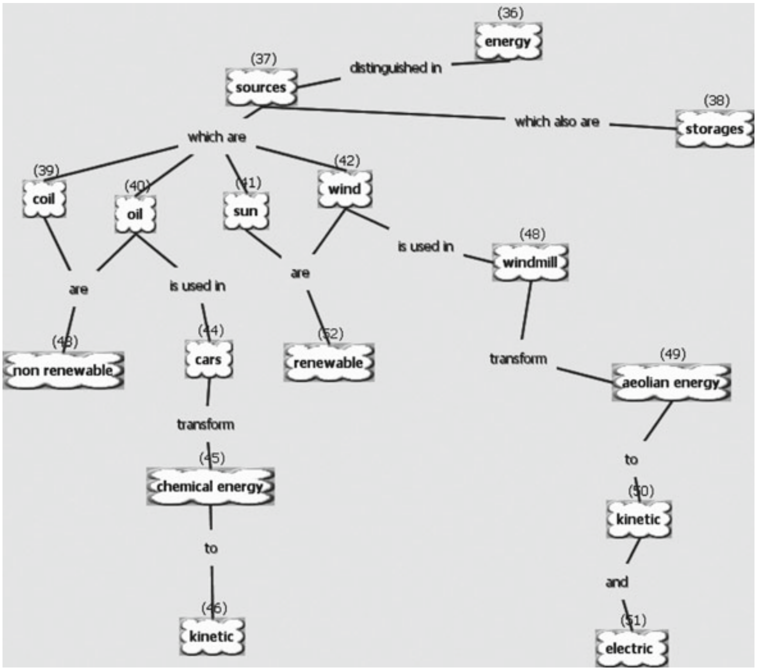

Fig. 8.2 Individual map, constructed after the first phase of instruction, of the second member of the group "Energy"

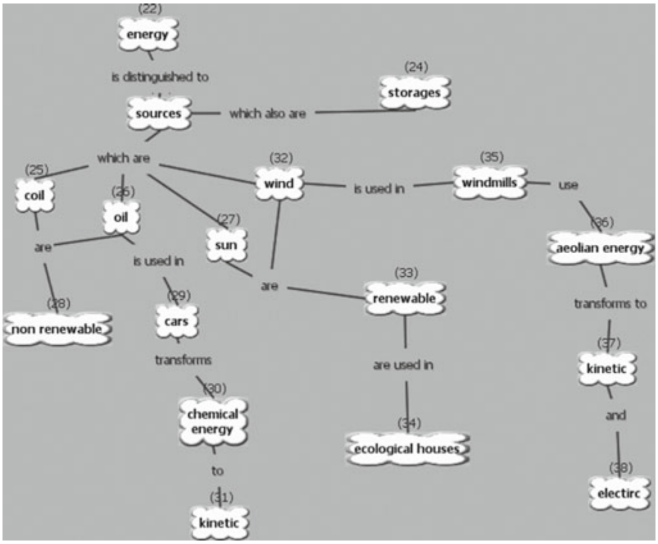

Fig. 8.3 Individual map, constructed after the second phase of instruction, of the second member of the group "Energy"

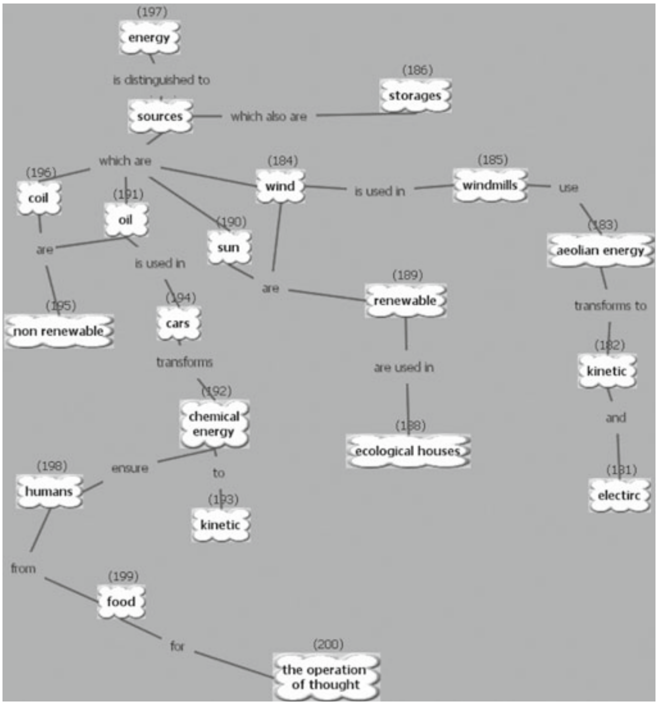

Fig. 8.4 Final individual map, constructed after the third phase of the instruction, of the second member of the group "Energy"

Table 8.1 Comparative analysis of individual knowledge maps sequence, second member, group "Energy"

		Before instruction	After first phase	After second phase	Final
Structure analysis	Structure type	Tree	Tree	Tree	Tree
	Conceptual strategy	Analysis ×2	Analysis ×4	Analysis ×4	Analysis ×5
		Connection ×2	Synthesis ×2	Synthesis ×2	Synthesis ×3
		Enrichment, providing additional piece of knowledge ×4	Enrichment, process description ×2	Enrichment, process description & providing additional piece of knowledge Listing pieces of knowledge	Enrichment, process description×2 & providing additional piece of knowledge Listing pieces of knowledge
			Listing pieces of knowledge		
Concept analysis	Number of concepts	9	15	16	20
	Type of concepts	2 school science concepts	9 school science concepts	10 school science concepts	10 school science concepts
		7 everyday life concepts	6 everyday life concepts	6 everyday life concepts	10 everyday life concepts
	Aspects of topic	2	3	4	5
Links, Labels, Proposition analysis	Number of propositions	11	17	19	21
	Label's variety	5/11 (0,4)	7/17 (0,4)	7/19 (0,4)	10/21 (0,5)
	Type of labels	3 one word	6 one word	6 one word	10 one word
		2 phrases	5 phrases	7 phrases	6 phrases
	Type of links	Plain	Plain	Plain	Plain
	Validity of propositions	Valid	Valid	Valid	Valid

The second member of the group “Energy” constructed a satisfying individual map before instruction as far as the concept and structure analysis is concerned. Its wide number of everyday life concepts is its basic defect, even though that this is expected due to the fact that is a “before instruction” map. Its concepts describe the relation between energy and living organisms, which is the student’s main representation. It is worth noticing that this student is the only one in the present research who recorded the representation about the identical energy sources and storages.

The present sequence of individual maps reveals a developmental knowledge construction. We have to emphasize the fact that the student based the structure of its maps on its main representation, without following the flow of the course and constructed his new knowledge using concepts from the instruction. Trying to study and describe his strategy we can say that the exploitation of a representation which is firm and according to the science model is able to lead to knowledge construction.

In order to study the collaborative learning the collaborative maps constructed before and after every phase of the course for every group was compared. The collaborative learning of the group “Energy” is a developmental process. It was noticed that at the construction of the collaborative map before instruction the first member seemed to exclusively influence the collaborative construction. That fact changed during the construction of the collaborative map after the first phase of instruction. In this case a whole part of the individual map before instruction of the second member is recorded at the collaborative map constructed after the first phase of the instruction. Additionally the following two maps during instruction record parallel influence of the two members to the collaborative construction.

Additionally, the final collaborative map is a better map than all the previous ones (Table 8.2).

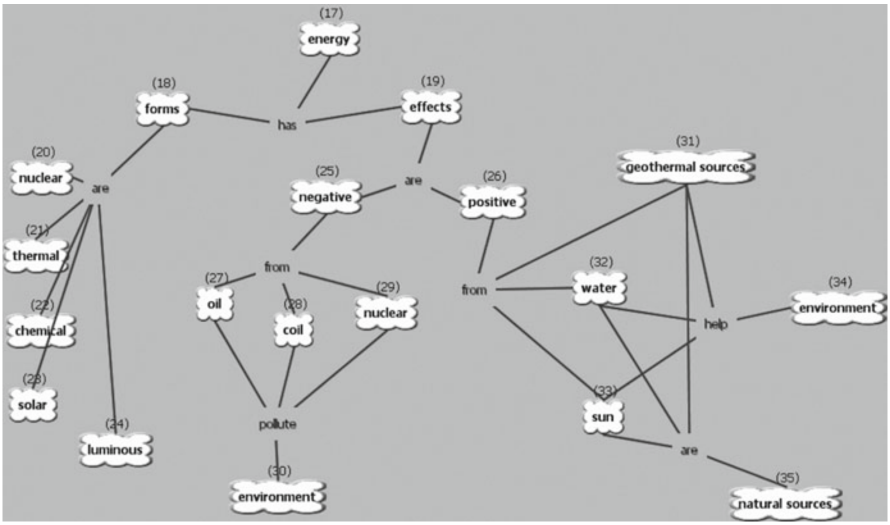

Fig. 8.5 Collaborative concept map, constructed before instruction, of the group “Energy”

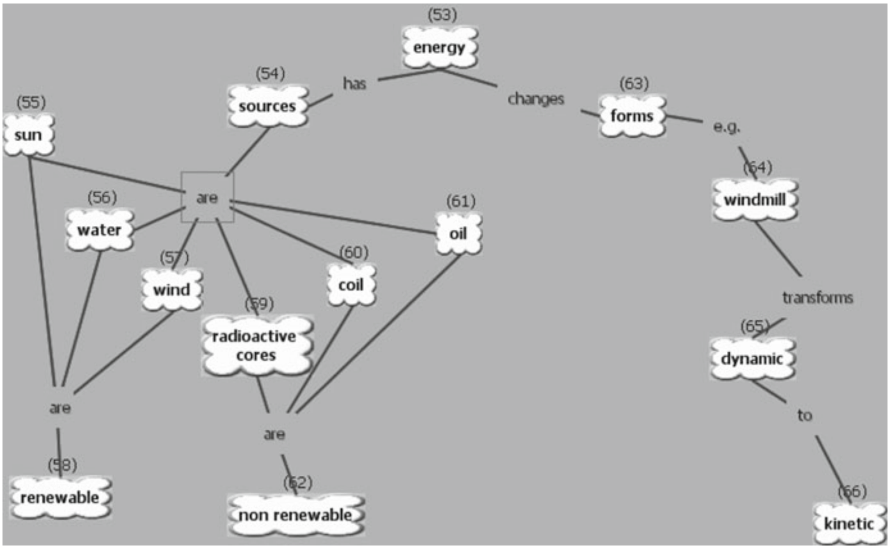

Fig. 8.6 Collaborative concept map, constructed after the first phase of the instruction, of the group “Energy”

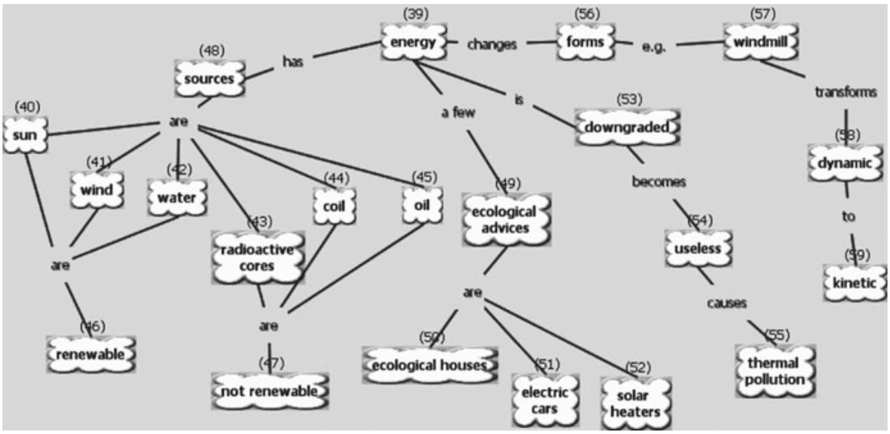

Fig. 8.7 Collaborative concept map, constructed after the second phase of the instruction, of the group “Energy”

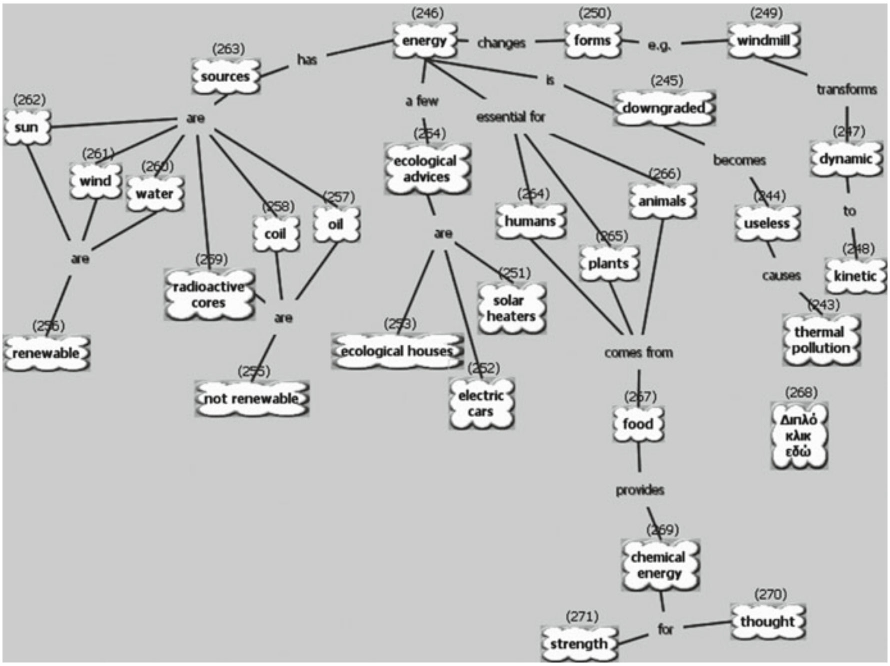

Fig. 8.8 Final collaborative map, constructed after the third phase of instruction, of the group "Energy"

In order to study the possible interactions between the members of a group, the individual maps constructed before instruction and after every phase of the course with the correspondent collaborative maps were compared. As far as the group "Energy" is concerned, its first member seems to exclusively influence the collaborative construction before instruction. The collaborative map before instruction is slightly better than the individual map of the first member and better than the individual map of the second member (Table 8.3).

Table 8.2 Comparative analysis of collaborative knowledge maps sequence, group "Energy"

		Before instruction	After first phase	After second phase	Final
Structure Analysis	Structure type	Tree	Tree	Tree	Tree
	Conceptual strategy	Analysis ×4	Analysis	Analysis ×2	Analysis ×5
		Connection ×3	Synthesis ×2	Synthesis ×2	Synthesis ×3
		Listing pieces of knowledge	Enrichment, process description	Enrichment, process description×2	Enrichment, process description×2 & providing additional piece of knowledge ×2
			Listing pieces of knowledge	Listing pieces of knowledge	Listing pieces of knowledge
Concept analysis	Number of concepts	18	14	21	28
	Type of concepts	11 school science concepts	9 school science concepts	13 school science concepts	14 school science concepts
		7 everyday life concepts	5 everyday life concepts	8 everyday life concepts	3 everyday life concepts
	Aspects of topic	3	2	4	5
Links, Labels, Proposition analysis	Number of propositions	24	17	24	32
	Label' s variety	5/24 (0,2)	6/17 (0,3)	10/24 (0,4)	14/32 (0,4)
	Type of labels	6 one word	7 one word	11 one word	14 one word
		2 phrases	1 phrase	2 phrases	3 phrases
	Type of links	Plain	Plain	lain	Plain
	Validity of propositions	Valid	Valid	Valid	Valid

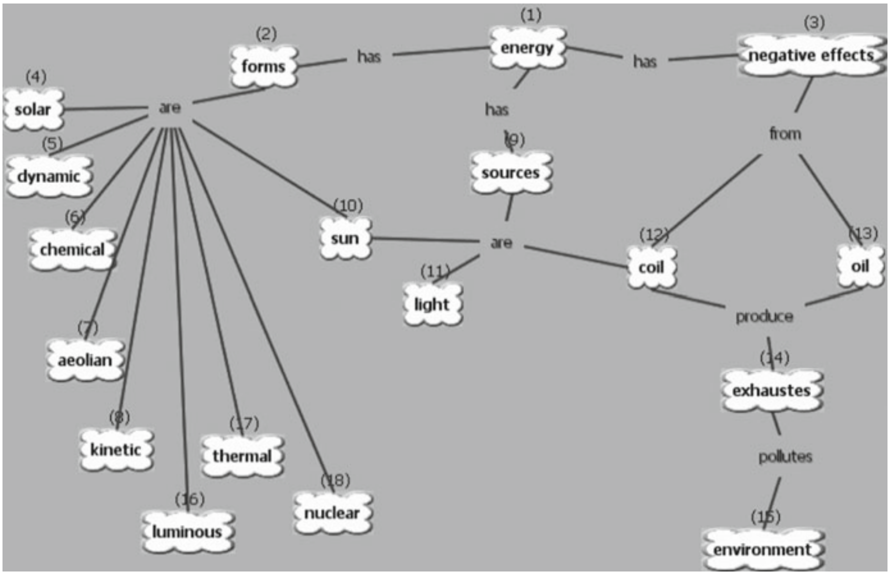

Fig. 8.9 Individual map, constructed before instruction, of the first member of the group "Energy"

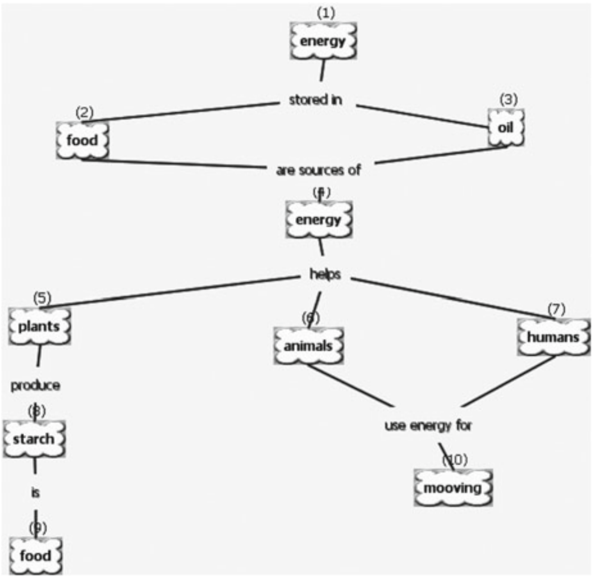

Fig. 8.10 Individual map, constructed before instruction, of the second member of the group "Energy"

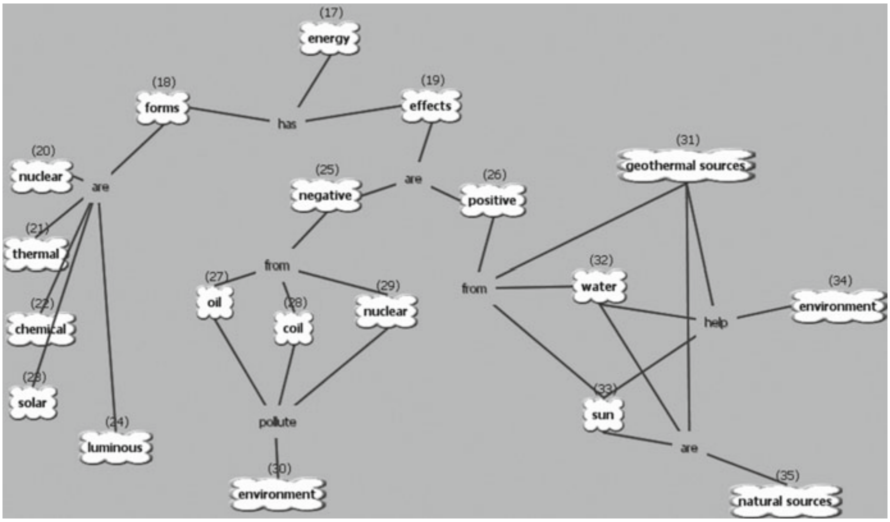

Fig. 8.11 Collaborative map, constructed before instruction, of the group "Energy"

Table 8.3 Comparative analysis of individual knowledge maps and collaborative map before instruction, group "Energy"

Before instruction		Individual map first member	Individual map second member	Collaborative map
Structure analysis	Structure type	Network	Tree	Tree
	Conceptual strategy	Analysis ×3	Analysis ×2	Analysis ×4
		Connection	Synthesis ×2	Synthesis
		Enrichment, providing additional piece of knowledge	Enrichment, providing additional piece ×2	Connection ×2
		Listing pieces of knowledge		Listing pieces of knowledge
Concept analysis	Number of concepts	18	9	18
	Type of concepts	12 school science concepts	2 school science concepts	11 school science concepts
		6 everyday life concepts	7 everyday life concepts	7 everyday life concepts
	Aspects of topic	2	2	3
Links, Labels, Proposition analysis	Number of propositions	20	11	24
	Label' s variety	5/20 (0,2)	5/11 (0,4)	5/24 (0,2)
	Type of labels	8 one word	3 one word	6 one word
			2 phrases	2 phrases
	Type of links	18 Plain	Plain	Lain
		2 cross-links		
	Validity of propositions	Valid	Valid	Valid

In order to study the possible influence of the collaborative learning on the individual learning every collaborative map with the individual maps which followed its construction was compared. The comparative analysis of the collaborative map constructed after the second phase of the instruction and the individual knowledge maps, constructed after the third, final phase of the instruction of group "Energy" resulted that both the individual maps are better than the collaborative one which was constructed before them. Thus, we are able to highlight that the instruction and the collaboration benefited both members (Table 8.4).

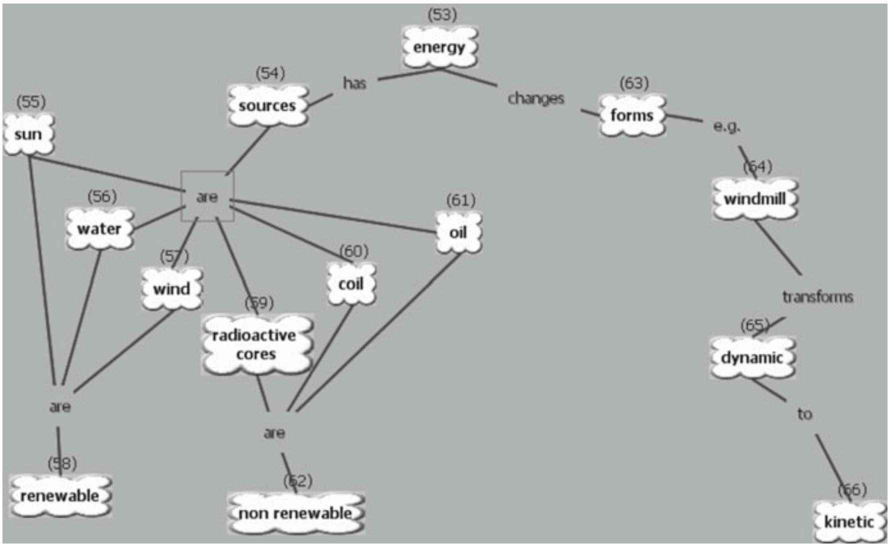

Fig. 8.12 Collaborative map, constructed after the second phase of the instruction, of the group "Energy"

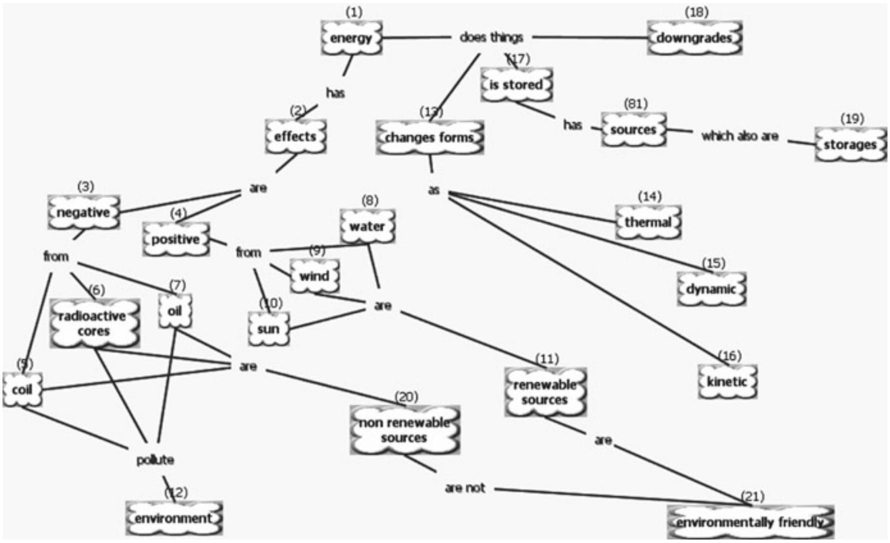

Fig. 8.13 Final individual map, constructed after the third phase of the instruction, of the first member of the group “Energy”

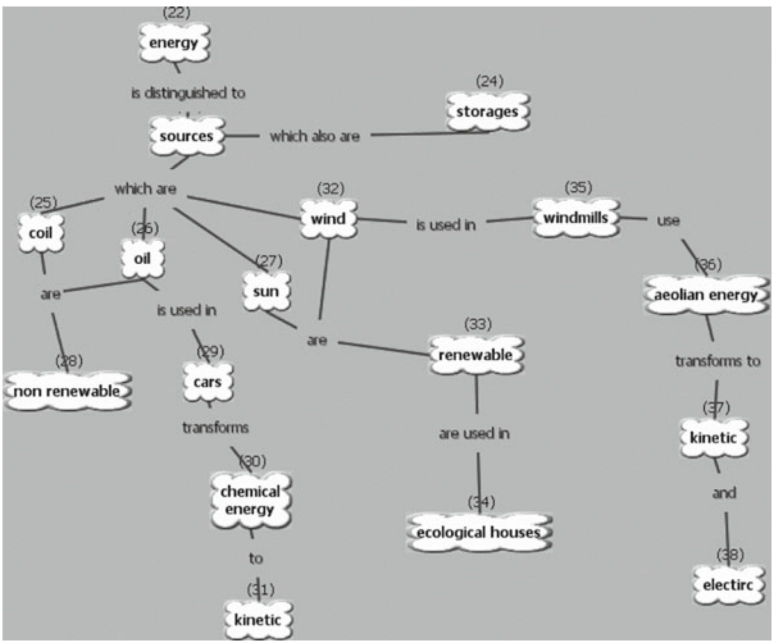

Fig. 8.14 Final individual map, constructed after the third phase of the instruction, of the second member of the group “Energy”

Table 8.4 Comparative analysis of collaborative map constructed after the second phase of the instruction and individual knowledge maps, constructed after the final phase of the instruction, group "Energy"

		Collaborative ma	Individual map first member	Individual map second member
Structure analysis	Structure type	Tree	Tree	Tree
	Conceptual strategy	Analysis ×2	Analysis ×6	Analysis ×5
		Synthesis ×2	Synthesis ×3	Synthesis ×2
		Enrichment, process description ×2	Enrichment, providing additional piece of knowledge ×4	Enrichment, process description×3 & providing additional piece of knowledge
		Listing pieces of knowledge	Listing pieces of knowledge	Listing pieces of knowledge
Concept analysis	Number of concepts	21	29	20
	Type of concepts	13 school science concepts	14 school science concepts	10 school science concepts
		8 everyday life concepts	15 everyday life concepts	10 everyday life concepts
	Aspects of topic	4	5	5
Links, Labels, Proposition analysis	Number of propositions	24	38	21
	Label' s variety	10/24 (0,4)	9/38 (0,2)	10/21 (0,5)
	Type of labels	11 one word	13 one word	10 one word
		2 phrases	3 phrases	6 phrases
	Type of links	Plain	Plain	Lain
	Validity of propositions	Valid	36 Valid 2 Nonvalid	Valid

5 Conclusion and Future Perspectives

It is believed that the research presented above succeeded in highlighting the use of knowledge maps as an alternative method. Particularly, to monitor closely and synchronously within the teaching procedure the individual and collaborative learning processes. Also, its use was proven appropriate and effectively in revealing conceptual representations. More specifically, the conceptual representations recorded tend to be preserved when they are cohesive. On the contrary, students usually abandon them when they are poor. Furthermore, when the two students of the group collaborated, the one with the individual map with better structure and content tends to affect more the construction of the collaborative map, which is always better than each individual. Finally, the member of the group which affects less the construction of the collaborative map usually adopts concepts from it when he constructs his new individual map. In addition, the advantage of using knowledge mapping software, concerning easy construction, revision, and storage were also revealed in practice.

The whole process raises various issues for discussion and places future research prospects. First of all, the question about how the conceptual maps can be used as an assessment tool with generally accepted reliability remains open. Our opinion is that an assessment protocol, as the one described, that combines the evaluation of qualitative and quantitative elements of a map and which is tested in various topics and by various evaluators, is able to fulfill the need for reliability. Also the process of construction, collection, and analysis of conceptual maps even if it becomes easier in a computer based environment is time-consuming enough. Thus, it raises the issue of the wide use of knowledge mapping in the school routine. Still in the present research the influence of the software in the learning process was not investigated. According to the relevant theory its influence exists and remains to be researched, possibly by the parallel construction of knowledge maps by pen and paper. Finally, the design of a collaborative environment also influences the learning results. In other words the choices made in the present research process concerning synthesis of the groups, didactical activities, cognitive tools, and learning strategies influenced the research results. Modifications of this methodology would constitute perspective for a new research study.

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Chapter 9
Towards a Cultural Historical Theory of Knowledge Mapping: Collaboration and Activity in the Zone of Proximal Development

John Cripps Clark

Abstract This chapter locates knowledge mapping within the theoretical framework of cultural historical activity theory. Cultural historical activity theory provides an analytic tool for understanding how knowledge maps can act as "stimuli-means": a cultural artefact that can mediate the performance of subjects (Vygotsky, 1978). Knowledge maps possess Vygotsky's double nature: they not only enable students to enact academic practice but also allow reflection on that practice. They enable students to build an "internal cognitive schematisation of that practice" (Guile, 2005, p. 127). Further, cultural historical activity theory gives the tools to analyse the social context of our use of knowledge maps and thus consider the mediating rules (tacit and explicit) and division of labour that mediate our use of knowledge maps. Knowledge maps can be viewed as acting within Brandom's (2000) *space of reasons*, which allows learners to use reasons to develop and exchange judgements based on shareable, theoretically articulated concepts and collectively develop the ability to restructure their knowledge and enact these judgements (Guile, 2011). In particular multimodal collaborative knowledge maps can act as Vygotsky's (Vygotsky, 1978) *zone of proximal development*, where teacher and peer-to-peer interaction allow students to solve problems and learn concepts and skills that they would be otherwise unable to tackle.

Keywords Cultural historical activity theory • Concept map • Zone of proximal development • Double stimulation

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1 Introduction

Apart from a frequent reference to Ausubel and Vygotsky (Novak & Cañas, 2006), knowledge mapping has generally concentrated on the empirical. Yet within cultural historical activity theory there are powerful ideas which could be used to interrogate knowledge mapping and, reciprocally, the analysis of knowledge mapping can provide insights into theory. This chapter outlines a number of ideas from cultural historical activity theory and associated theoretical lenses which could inform the analysis and use of knowledge maps.

Cultural historical activity theory is a framework for systematically analysing human activities in context: “a powerful analytic tool that helps to reveal the fundamental aspects of social practice, and support structured, meaningful interpretations of empirical data” (Kaptelinin & Miettinen, 2005, p. 1).[1] It was developed within the Moscow school of cultural-historical psychology in Soviet Russia, notably by Vygotsky and Leont’ev, between the 1920s and 1970s before moving to the west and being further developed by social researchers. Within the theory, activity is framed as intentional, object orientated and directed towards creation of outcomes (physical or mental). Mental activity does not prefigure physical activity but the physical and mental are inextricably bound to each other (Leont’ev, 1978). Thus knowing can only be understood in the context of doing “you are what you do” (Vygotsky, 1978) and vice versa. The great utility of cultural historical activity theory is that it is a realist theory that enables systematic analysis of social activity in context: it highlights the most important factors that affect the activity and provides a language with which to analyse these. It is a mid-level theoretical tool, which unites different communities of scholars and links disparate discourses. Below I explicate some of the ideas from within the cultural historical activity theory tradition which provide analytic lenses through which to analyse multimodal collaborative knowledge maps: mediation, activity theory, double stimulation, zone of proximal development, collaboration in the space of reasons, and ascent from abstract to concrete.

2 Mediation

> The idea of mediation … runs as the unifying and connecting lifeline throughout the works of Vygotsky, Leont’ev, Luria and the other representatives of the Soviet cultural-historical school. (Engeström, 1999, p. 21)

The idea of mediation was used by Hegel in terms of ideas and by Marx in terms of objects: “Man uses the mechanical, physical, and chemical properties of objects so as to make them act as forces that affect other objects in order to fulfil his

[1] Kaptelinin and Miettinen are referring to the object of activity rather than cultural historic activity theory but the description is apt to both.

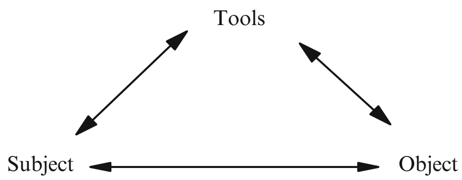

Fig. 9.1 Tools mediate between subject and object (Vygotsky, 1978)

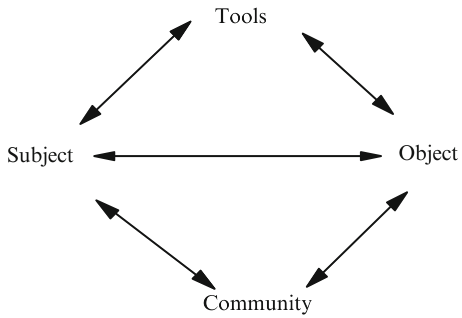

Fig. 9.2 Community as a mediator between subject and object (Leont'ev, 1978)

personal goals" (cited in Vygotsky, 1978, p. 54). Vygotsky combined these two aspects of mediation: "Mediators are understood to be twin entities that have both material and ideal properties simultaneously" (Zinchenko, 2001, p. 283).

> A fundamental assumption of Activity Theory is that tools mediate or alter the nature of human activity and, when internalised, influence humans' mental development. (Jonassan & Rohrer-Murphy, 1999, pp. 66–67)

Vygotsky proposed that the action of the subject on the object could be mediated by tools (or artefacts or instruments) as shown in Fig. 9.1. These tools can be physical, cultural or mental. For example, a tool could be a calculator, pedagogy, language genre, or knowledge map.

The tools node is not just an alternative pathway for the activity; it fundamentally changes the activity. The subject is able to achieve different outcomes using a tool and in turn the subject is changed. "[Mediating tools] possess the specific function of reverse action, it transfers the psychological operation to higher and qualitatively new forms and permits the humans, by aid of extrinsic stimuli, *to control their behaviour from outside*" (Vygotsky, 1978, p. 40, emphasis in the original). Mediating tools can be internalised: "Mediation is how culture enters psychological processes and shapes behaviour" (Guile, 2005, p. 126).

> "The person, using the power of things or stimuli, controls his own behaviour through them, grouping them, putting them together, sorting them. … He changes the environment with the external activity and in this way affects his own behaviour, subjecting it to his own authority." (Vygotsky, 1987b, p. 212)

To emphasise that activity is socially located and the community around the activity profoundly affects and is affected by the activity (Leont'ev, 1978) proposed that we consider the community as a mediator, as shown in Fig. 9.2.

3 Activity Theory

Yrjö Engeström (1992) has introduced two other mediators: rules and division of labour, to create a network (Fig. 9.3) which can act as an analytic tool which is particularly useful in analysing the contradictions in the activity system which can either derail the activity or drive change to new forms of activity.

The words used in activity theory clearly have a meaning that is historically contingent. Thus Vygotsky and Leont'ev used the word "deyatelnost", a word with no equivalent in English, but for which the word "activity" is generally used (Wertsch, 1985). Activity Theory has developed within several small groups in specific historical and cultural contexts.

Activity: This is the basic unit of analysis. Activity is both directed and conscious. It can be described as the process of a *subject* producing an *outcome* by acting on an *object*. Thus, in this case, the teacher is aiming to produce learning in students by acting upon their knowledge of science.

Subject: The subject can be an individual or a group. It is their agency in the activity that provides the focus of the analysis. In this study the teacher is the subject but it could equally be an individual student or a group of students working together on the practical activity. In any social context there may be multiple activity systems with different subjects but overlapping objects.

Object: Can either be viewed as the objective of the activity or the object on which the activity acts: "the 'raw material' or 'problem space' at which the activity is directed and which is moulded and transformed into outcomes" (Roth & Tobin, 2002, p. 113) or "what you have to shift to get to the outcome" (Daniels, 2005, p. 1). The object is both material and ideal (Foot, 2002); it exists in the physical, mental and cultural world.

Tools: One of Vygotsky's many great insights was the realisation that physical and mental tools can influence the subject acting on the object; these tools mediate the relationship between subject and object.

Community: Leont'ev's contribution was to find a way to express the social nature of humans within activity systems by describing the community, which acts a mediator between subject and object, in an equivalent way to the tools (Leont'ev, 1978).

Rules: These can be explicit and implicit and mediate the way in which the subject and community interact.

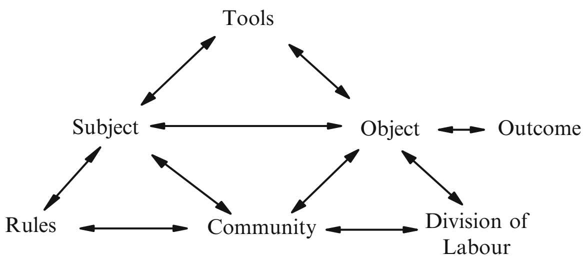

Fig. 9.3 Activity system, triangle representation (Engeström, 1999)

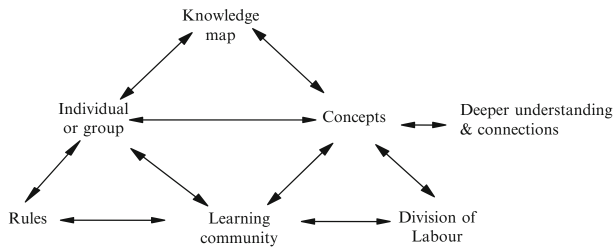

Fig. 9.4 An activity triangle for knowledge mapping

Division of labour: Since the outcome producing activity occurs within a social context there is inevitably some distribution of actions within the community. *Division of labour* can be interpreted as *social role* which mediates between the community and subject (see for example (Cripps Clark, 2001, 2003; Spasser, 2002).

A proposed activity triangle for knowledge maps used in the activity of learning or teaching concepts is shown in Fig. 9.4. Below a number of ideas from cultural historical activity theory which have a relevance to knowledge mapping are raised.

4 Double Stimulation

Within Vygotsky's project of developing a new psychology in which social mediation of the "higher mental functions" was central, he proposed the mechanism of double stimulation. Vygotsky developed the idea of double stimulation to understand the interaction between everyday and scientific concepts in development. In double stimulation a neutral object (a knowledge map) becomes a tool for the development of higher mental functions (understanding the relationships between concepts and thus the concepts themselves). Vygotsky explained double stimulation as a way of both stimulating thinking and investigating thought through the objectification of psychological functions:

> In such cases a neutral object is placed near the child, and frequently we are able to observe the neutral stimulus is drawn into the situation and takes on the function of a sign. Thus, the child actively incorporates these neutral objects into the task of problem solving. … We simultaneously offer a second series of stimuli that have a special function. In this way, we are able to study the process of accomplishing a task by the aid of specific auxiliary means; thus we are able to discover the inner structure and development of higher psychological processes. (Vygotsky, 1978, pp. 74–75)

In refining these ideas Vygotsky introduced the idea of the social mediation of intellectual development where higher psychological functions are initially manifest collaboratively and are then internalised. Knowledge mapping is an example of double stimulation since "it pushes the subject to go beyond the problem initially given, to open up and expand upon an object behind the problem" (Engeström, 2009, p. 303).

Knowledge mapping also act as an external memory field, which externalises, crystallises and objectifies concepts in the same way as Feynman diagrams. Richard Feynman, awarded Nobel Prize in Physics in 1965 with Tomonaga and Schwinger for their work on quantum electrodynamics is famous for his *Feynman diagrams* which enable the communication and analysis of quantum field states visually: "in simple and natural terms, rather than only abstract mathematical ones" (Mehra, 1996, p. 287). Like knowledge maps, Feynman diagrams are examples of the way "writing and visualization allow human beings to establish a theoretic culture based on gradually accumulating the external symbolic storage systems" (Ritella & Hakkarainen, 2012, p. 242). Feynman explained in an interview by the MIT historian Charles Weiner:

> Weiner once remarked casually that his new parlton[2] notes represented "a record of the day-to-day working," and Feynman reacted sharply.
>
> "I actually did the work on the paper," he said.
>
> "Well," Weiner said, "the work was done in your head, but the record of it is still here."
>
> "No, it's not a *record*, not really. It's working. You have to work on paper, and this is the paper. Okay?" (Gleick, 1992, p. 409)

5 Zone of Proximal Development

The zone of proximal development is an influential metaphor for learning as a social process. As with the mediation provided by tools such as knowledge maps, the mediation provided by the teacher and students enables students to solve problems and learn concepts and skills that they would not be able if unassisted. A useful way of describing this mediation is to use Vygotsky's zone of proximal development, which describes students' developmental potential in terms of the difference between what can be achieved on their own and with assistance.

Vygotsky's most commonly quoted definition of the zone of proximal development is:

> … the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1978, p. 86)

or more succinctly: "what the child is able to do in collaboration today he will be able to do independently tomorrow" (Vygotsky, 1987a, p. 211).

Understanding the student's zone of proximal development and teaching within it is important because this where the student's maturing psychological functions, necessary for the next stage, can be developed (Chaiklin, 2003). It is assumed that a student can only make use of the expert guidance or collaboration with a more

[2] *Parlton* was a term invented by Feynman to explain interactions within protons. It was subsequently overtaken by the more successful *quark* (see Gleick, 1992, pp. 387–396).

capable peer if they have the developing psychological functions that are necessary in the "proximal and subsequent periods of his stage of development" (Vygotsky, 1987c, p. 203).

Vygotsky found that zone of proximal development was a better predictor of children's intellectual development than their present IQ but did not give a systematic account of how one could assess a students' zone of proximal development in practice (Chaiklin, 2003). His most detailed account is:

> We show the child how such a problem must be solved and watch to see if he can do the problem by imitation, demonstration, or we begin to solve the problem and ask the child to finish it. Or we propose that the child solve the problem that is beyond his mental age by cooperating with another, more developed child or, finally, we explain to the child the principle of solving the problem, ask leading questions, or analyse the problem for a minute. (Vygotsky, 1987c, p. 202)

Imitation is a term Vygotsky used to describe the interaction with a more competent person around a specific task that the student would not otherwise to do (Chaiklin, 2003). Imitation depends on the context of the assistance, the person who is assisting, and the type of assistance given. In attempts to operationalise the concept of zone of proximal development a number of types of assistance have been suggested (Brophy, 1999; Coltman, Petyaeva, & Anghileri, 2002; Tharp, 1992). Some of the assistance strategies suggested include:

- Encouraging and drawing attention to relevant issues in relation to the task;
- Giving a framework for the problem;
- Asking leading questions;
- Demonstrating the actions necessary to solve the task using an equivalent context;
- Comparing performance to a standard;
- Directing the student towards particular strategic pathways, and away from others;
- Sequencing and structuring the task;
- Structuring new cognitive operations through questions and explanations;
- Initiating the task and gradually withdrawing assistance; and
- Direct instruction.

Vygotsky's zone of proximal development was a theoretical and practical tool to understand children's development of their integrated psychological functions from one stage to the next; it was not a tool to examine learning (Chaiklin, 2003). For this the term *scaffolding* is useful. Although *scaffolding* does not appear in Vygotsky's work (Verenikina, 2003) the metaphor has become popular among teachers as a way of encapsulating some of the ideas of the zone of proximal development: "'scaffolding' is an attractive concept for both psychology and education because it offers a neat metaphor for the active and sensitive involvement of the teacher in a students' learning" (Mercer, 2000, p. 73). In particular it captures the ideas, important to teachers, of *challenge* and *support* (Mariani, 1997). An important element of scaffolding is the modelling of effective strategies of thinking and communication by the teacher (Rasku-Puttonen, Etelaplelto, Hakkinen, & Arvaja, 2002).

Radziszewska and Rogoff (1991) found that the knowledge of children improved with adult guidance but not with the assistance of more knowledgeable peers.

This was largely because the adults used guided participation, and in particular modelling effective strategies of thinking and communication (Rasku-Puttonen, Etelaplelto, Hakkinen, & Arvaja, 2002).

The role of play in the zone of proximal development is important because "the child moves forward essentially through play activity" (Vygotsky, 1978, p. 103). Vygotsky (1933/1966, online) argued that "play is the source of development and creates the zone of proximal development." Leont'ev (1981) explained that this activity "contributes in a decisive way to the development of the child by promoting new actions and psychological processes that anticipate a new episode of development."

The existing knowledge and skills are a function of students' past experiences both inside and outside the learning environment, their everyday knowledge and skills, and the attitudes they have developed as a result of these experiences. Vygotsky (1978) showed how, when students acquire new subject knowledge and skills, it extends the meaning of their existing knowledge and skills, and that the new knowledge and skills only become functional when they are integrated into existing knowledge and skills. The zone of proximal development reminds us "context and capacity are inextricably entwined" (Lee & Smagorinsky, 2000, p. 2).

Using knowledge maps both the teacher and other students can scaffold knowledge building. Knowledge maps allow the creation of multiple, overlapping zones of proximal development. This provides students with a variety of challenges, at various levels of sophistication that students working individually or in groups need to solve. Thus, in suitably structured classroom environments, students can scaffold each other in the development of knowledge maps. Moreover greater freedom and complexity enables students to display many of the characteristics of play, which is important for children's development.

6 Collaboration in the Space of Reasons

In the first chapter of this book Hanewald and Ifenthaler observe the collaborative capacity of knowledge mapping tools. Cultural historical activity theory also provides the ideas that can be deployed to analyse the social context and thus consider the rules (tacit and explicit) and division of labour that mediate our use of knowledge maps. Knowledge maps can be understood within Brandom's (2000) "space of reasons". Brandom (2000) argues that we locate concepts and ideas in the space of reason via the "social practice of giving and asking for reasons" (p. 3). This allows learners to use reasons to develop and exchange judgements based on shareable, theoretically articulated concepts and collectively develop the ability to restructure their knowledge and enact these judgements (Guile, 2011): "in characterising an episode or a state as that of knowing, we are not giving a logical description of that episode or state; we are placing it in the logical space of reasons, of justifying and being able to justify what one says" (McDowell, 1996, p. iv).

There is strong evidence that peer-to-peer and group learning is vital in education (Adams, 2004; Britton & Anderson, 2010; Devenish et al., 2009; Feryok, 2009;

Manouchehri, 2002; McLoughlin, Brady, Lee, & Russell, 2007). Learning is much more than the acquisition of existing knowledge and skills but rather developing the ability to interpret and respond to problems that are explicitly embedded in existing and future social practice (Edwards, 2005). This necessitates the creation and maintenance of communities of learning.

Knowledge maps can provide the focus for communities of learning in which we create a space of reasons. Within the changing environment and expectations of contemporary education we need to generate a zone of proximal development which, in terms of Lave and Wenger's (1991) social interpretation, reveals the difference between current knowledge and new forms of knowledge which are collectively generated from the contradictions of present practice. Contradictions play an important role in cultural historical activity theory by providing the philosophical and practical impulse for change: "The distance between the present everyday actions of the individuals and the historically new form of the societal activity that can be collectively generated as a solution to the double bind potentially embedded in the everyday actions" (Engeström, 2000, p. 174). There is a fertile correspondence between the concepts of zone of proximal development and space of reasons (Derry, 2008). We need to construct learning environments which distribute learning across tools (including but not limited to digital technologies), artefacts (including learning objects) and social groupings. We cannot do this merely with new forms of technology: we need to give profound attention to the way students, staff, the professions and the community interact.

There is a more substantial concern lurking behind these considerations, namely the moral dimensions of our interaction with others. As Edwards (2005) points out, working together is a moral as well as a cognitive process. Hicks (2000) argues that we need to move beyond the dialogic analysis of learning (Mercer, 2000; Mercer & Howe, 2012; Wells, 2007) to the moral dimensions of engaging in sense and value making with others. We have seen a more subtle argument about these issues from conservative philosophers (Sennett, 2012; Taylor, 1991) and it behoves us to engage with these ethical issues as we construct learning objects and environments.

7 Davydov and the Ascent from Abstract to Concrete

One of the more challenging ideas to emerge from Vygotskian educational psychology in Russia is Davydov's *ascent from abstract to concrete*. It is of interest here because this neat reversal of Piagetian developmental stage theory gives us a deeper understanding of the power of knowledge mapping. Vasily Davydov (1930–1998) drawing on the ideas of the philosopher Evald Il'enkov (1924–1979) (Bakhurst, 2005) and working closely with Daniel Elkonin (2005) developed a detailed and prescriptive theory of learning activities which sequentially reproduces the historical formation of a concept from a "germ cell", an abstract but simple explanation, through the revelation and resolution contradictions (Davydov, 2008). The initially simple concept is transformed via a series of comparisons and classifications which the empirical into a more complex interconnected network of concepts.

Engeström and Sannino (2010) summarise the specific steps in Davydov's sequence as:

1. Transforming the conditions of the task in order to reveal the universal relationship of the object under study;
2. Modelling the identified relationship in a material, graphic or literal form;
3. Transforming the model of the relationship in order to study its properties in their "pure guise";
4. Constructing a system of particular tasks that are resolved by a general mode;
5. Monitoring the performance of the preceding actions; and
6. Evaluating the assimilation of the general mode that results from resolving the given learning task (p. 5).

Davydov's ascent from the abstract to the concrete not only reveals the theoretical roots of the empirical success of knowledge mapping but also opens new routes continue to develop knowledge mapping.

8 Collaboration Between Knowledge Mapping and Cultural Historical Activity Theory

There has been limited use of cultural historical activity theory ideas within knowledge mapping research and only rarely have the resources of theory been used to interpret the mechanisms of knowledge mapping. Novak and Cañas (2006) deploy the idea of zone of proximal development to advocate knowledge mapping in small groups selected on the basis of similar zones of proximal development. Baldón and Berionni (2006), analysing the use of concept maps by elementary science students, also use the idea of zone of proximal development but in order to construct a space of reason in which playful dialogue, and thus learning, can occur. Van Boxtel et al. (2002) also consider collaboration in a physics class to understand the role of concept maps in the "articulation, elaboration, and co-construction of meaning and sense" (p. 45). Stoyanova and Kommers (2002) use activity theory to set up a quantitative experiment in which they demonstrate the efficacy of *shared* group interactions during knowledge mapping over *distributed* and *moderated* interactions but fail to use the theory to interrogate the mechanisms. In a reversal of the usual approach, Kinchin, Hay and Adams (2000) use concept maps a way of determining students' zone of proximal development rather than zone of proximal development as way of interpretation of knowledge maps. In order to understand how concept maps work to develop understanding of concepts Aguilar-Tamayo and Aguilar-Garcia (2008) deploy Vygotsky's ideas about the relationship between everyday and scientific concepts. In a similar manner Moreira-Unisinos (2010) uses Bakhtin's (1981) ideas about genre to interpret the use of concept maps within schools.

There is a rich repertoire of analytic interpretative resources out of cultural historical activity theory which can be used to analyse the tool of knowledge maps and the activity of knowledge mapping which are summarised in Fig. 9.5 by being mapped onto the activity triangle (Fig. 9.4).

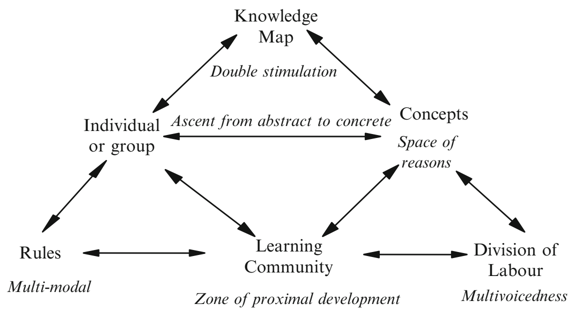

Fig. 9.5 Cultural historical activity theoretical ideas framed within the activity triangle

The mapping of these analytic tools, itself a knowledge map, can be used to guide research. Thus when we examine how knowledge maps mediate concept development we can use Vygotsky's idea of double stimulation; when we consider the social in knowledge maps we can (and have) employ the idea of zone of proximal development; Bakhtin's ideas of multivoicedness can inform our understanding of how a learning community interacts in the production and use of knowledge maps; and both Brandom's idea of space of reasons and Davydov's ascent from the abstract to the concrete can provide new ways of thinking about the role of knowledge maps in concept development.

Knowledge maps can be interpreted as a tool, in both the Vygotskian (1934/1987) and Novak and Cañas' (2006) sense. However, rather than seeing knowledge maps as merely an object, cultural historical activity theory encourages the view of knowledge mapping as an activity: a collaborative, multimodal tool of development. Cultural historical activity theory has identified mediation, double stimulation, zone of proximal development and ascent from the abstract to the concrete as mechanisms through which knowledge maps have the potential to nurture development. If we are to continue to enjoy a fruitful collaboration between knowledge mapping and cultural historical activity theory we need theoretically informed empirical research on these mechanisms.

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Chapter 10
Developing Australian Undergraduate Students' Science Communication Skills Through Collaboratively Created Digital Knowledge Maps

Ria Hanewald and Dirk Ifenthaler

Abstract This chapter describes the use of digital knowledge maps within a Science Communication course taught at an Australian University—across a rural and a metropolitan campus—with the view of increasing learning outcomes in future years. It explores the impact and extent of the students' learning, especially their prior knowledge, their attitude about working collaboratively in small groups, their perspective on using technology rich learning in general and using digital knowledge map in particular. In this 2011 study, 93 science communication students participated out of a total enrolment of 118 undergraduates. The knowledge maps were constructed in small groups of three to four students to allow for discussion and reflection. Topics for each map such as "Time travel", "Alzheimer's disease", "Genetically modified food", were chosen from the natural science, particularly biology, physics, chemistry and the earth sciences. Most students had little and some even no prior knowledge of knowledge mapping. Although taught by five different tutors across two campuses, the differences in learning outcomes between the rural and metropolitan setting were negligible. More than half of the students indicated that digital knowledge mapping helped them think about their topic.

Keywords Undergraduates • Science communication • Collaborative • Knowledge map • AKOVIA

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1 Introduction

The research focus for this study was to investigate the extent of a number of variables on student learning, specifically their (1) geographic location, (2) level of prior knowledge, (3) their attitude and experience of group work, (4) their views on technology-based learning and (5) their perception of their learning attainments after the completion of a study unit. The insights gained from the collected data are to be used to improve teaching strategies and amplify learning outcomes in the years to come.

2 Background Context

Geographic location in Australia is associated with differences in access to resources and opportunities, with rural areas indicating educational disadvantage and the inequality flowing on to employment inequality. Hence, higher education settings in rural contexts may be perceived by students as less desirable with inferior courses and teaching. Part of this research was to either confirm or dispel this widely held perception and investigate this equity argument. Hence, undergraduate students from the same Australian universities enrolled in the identical course—but attending either a rural or a metropolitan campus—were participating in this study.

Academics (that is course coordinator and lecturers) lecturing in first year university student cohorts base their units of work and standard of teaching and learning activities on the assumed prior knowledge base of the secondary school curriculum. The Science Curriculum, particularly Years 11 and 12 strongly supports linking science with learning literacy skills as articulated in its aims and structure by the Australian National Curriculum Board. Highlighted are participation in group discussions and the union of science and technology. While it does not mandate particular technologies it recognises "…the possibility that digital technologies provide for helping students understand science" (Australian National Curriculum Board, 2009, p 12). It points to some of the available technologies such as digital images, Internet-based inquiry resources, computer simulations and probeware tool that can help to engage students. On the basis of that, it is often concluded by science educators in tertiary settings that post-compulsory students are familiar with digital knowledge mapping as it is arguably one of the signature pedagogies of science. Shulman (2005) described signature pedagogies as the types of teaching that structures the fundamental ways in which people are educated in their profession, implying not only the knowledge of the field but also the way in which this knowledge is transferred. Thus, signature pedagogies are the fundamental ways in which future practitioners are educated and used to from the "habits of the heart, mind and hand".

Academics assuming undergraduate students' familiarity with knowledge maps are approaching their teaching with an assumption of prior knowledge that may not necessarily be in existence. This perception of learner knowledge and competencies in learners is directly correlated to the level of teaching that academics pitch their lectures and tutorials. A miss match may result in frustrations not only amongst students but also teaching staff as well as lost learning opportunities. Therefore, it was seen as crucial to establish a benchmark of pre-existing proficiencies, which this study attempted to do through surveys administered to the undergraduate students.

Students' attitude and experience of group work was another focus of this study as the literature (Coutinho, 2009; Kwon & Cifuentes, 2007; Hwang, Shiu, & Chu, 2011) indicates that collaborative work in small groups on knowledge maps is more beneficial than individual work. Coutinho (2009) found in her study of 29 in-service teachers that collaboratively constructed knowledge maps scored higher than those created individually. She argued that teams that are communicating and interacting while constructing their maps go further in their understanding of the content than individuals who do not have the opportunity to debate and negotiate meaning with others while building their knowledge map. Kwon and Cifuentes (2007) had 161 students participating in their study, which they divided into two groups: those working on their own and those working in pairs. Both groups improved on comprehension tests about the concepts they had learned although the students who were working collaboratively produced higher quality knowledge maps (compared to those produced individually) and presented deeper conceptual understandings.

Hwang et al. (2011) divided their 70 students into three groups: one group worked collaboratively on digital knowledge maps, a second group used paper and pen to draw knowledge maps and the third group studied without any knowledge mapping. All students were pre-tested without any significant difference. The post-test indicated that students creating collaborative digital knowledge maps to study achieved significantly higher learning outcomes than those students who studied in other ways. In addition to greater learning achievements, students also had enhanced attitudes towards science learning, improved confidence and expectation of collaborative learning, greater interest in studying and more willingness to communicate and work with their fellow students.

In summary, it seems that the reasons for better outcomes of collaborative work is the ability of group members to deliberate what the key concepts are and in what way they are connected in terms of their hierarchies. By discussing the inclusion of certain concepts and their relationships, group work helps the clarification of concepts and their information as well as the detection of any erroneous or missing information. This robust debate and reflection inform the learning of team members and enhances the quality of the knowledge map. It was therefore seen as important to explore in which way students learn in groups and how that learning can be further heightened.

Students' views on technology-based learning were part of the investigation as anecdotal observations and vignettes collected by academics over several years seem to reveal a low level of technological proficiency in the majority of undergraduates, often also combined with a lack of interest in technology. These incidental accounts are in stark contrast to the literature which portrays the "Net Generation" as highly digital literate. Oblinger and Oblinger (2005, p 2.2) define Net Gen as

> Born around the time the PC was introduced, 20 % began using computers between the ages of 5 and 8. Virtually all Net Gen students were using computers by the time they were 16–18 years of age.

They argued that the exposure to Information Technology at an early age has given them substantial digital literacy skills, the ability for non-text expression (i.e. audio, video, graphics) and a penchant for multitasking.

Prensky (2010), who uses the term "millennial learners" or "Millennials" to label the same cohort, believes that they are intuitive, visual communicators, who learn better through discovery than traditional talk-based teaching. Millennials move seamlessly between the physical and visual world, quickly shifting their attention from one task to another to "get them done" while omitting unexciting ones. He asserted that these Net Gen students use technology as a tool for learning essential skills, are experts at finding, analysing and presenting content and enjoy working collaboratively with an expectation of rapid messages exchanges.

Similarly, Howe and Strauss (2000, 2007) described millennial learners as captivated by new technologies, drawn to group activities, engaged in a range of extracurricular tasks and focussed on outcomes and performance (their marks/assessment grades).

However, Kennedy and colleagues (2008, p 108–122) cautioned against such generalisations of Net Gen students. Assuming that Millennials enter universities with more or less homogenous technological experiences and digital literacy overlooks in these scholars' opinion the complex mix of skills, knowledge and preferences within that student cohort.

Regardless of these divergent views on Net Gen or Millennial students, all scholars agreed that this cohort need to be educated for a rapidly emerging, global and digital work environment. McArthur, McIntyre and Watson (2007) declared that Net Gen will work in professional collaborations across cultural, geographical and sometimes even disciplinary borders. These conditions not only challenge educators to develop online team-based learning to equip students with collaboration and communication skills to enable working successfully in these settings but also highlight the need for educators to pursue higher levels of understanding in regard to online collaboration learning and to adopt online pedagogical approaches that successfully engage students. Furthermore they argued that graduates need industry relevant core competencies and skills alongside higher order communication skills, innovation and creative thinking skills as well as problems solving and collaborative teamwork skills.

Net Gen's perception of their learning attainments after the completion of a tertiary unit of work was part of the research endeavour to establish their satisfaction with the curriculum and learning activities given that the teaching approach focused on nurturing their values, thoughts and actions as beginners in a specific field and the conveyance of a distinct practice that defines their hosen discipline.

3 Research Questions and Hypotheses

Given the aforementioned considerations outlined, the following research questions were formulated:

1. Are there any differences in learning outcomes between students attending a rural or a metropolitan campus?
   (a) Is there an educational disadvantage between geographic locations? If so, to what degree does it exist?
2. What prior knowledge do undergraduates have with knowledge maps?
   (a) How can working with knowledge maps help students in evaluation and synthesis of their learning, that is explicitly integrate new and old knowledge?
3. How do students work collaboratively on knowledge maps in small groups?
   (a) How students generate ideas/key concepts on a given topic individually and collaboratively and how that process can be supported by digital knowledge mapping?
   (b) How can knowledge mapping aid students in identifying information, finding and then using that information to construct comprehensive visual displays of a given topic?
   (c) How knowledge mapping can assist students in cultivating complex judgmental skills such as critical analysis and problem solving?
4. Do Net Gen students prefer digital knowledge maps to manual ones?
   (a) How do electronic knowledge mapping technologies enhance learning either individually or in collaborative teams?
5. What quality of learning can be expected under these circumstances?
   (a) To what extent do visual representations/knowledge maps allow for development of a more holistic understanding compared to a simple memorising of facts and recall (rote) approach?
6. How can the students' learning outcomes are improved in future years?

It was hypothesised that (1) Assumed differences in the literature regarding educational disadvantages in rural and metropolitan locations will be either non-existent or not significant differences between geographic locations of tertiary institutions as university quality assurance processes and systems will control and diminish any inequities between teaching standards across their campuses; (2) The vast majority of Australian undergraduate students will be highly familiar with knowledge maps as it is a teaching and learning strategy embedded in the secondary school curriculum and as such well-known and repeatedly practised which will impact on the design of the tertiary curriculum and learning activities; (3) There will be a preferred way of working by the students—either individually, in pair, small groups or large groups—which is identifiable and either confirms or challenges the existing literature on this issue, identification which will assist with the design of future learning activities and the desired improvement of learning outcomes; (4) Today's undergraduates are not highly techno savvy with a preference of digital modes over manual modes as the body of literature assumes but are techno tired and prefer physical strategies for learning over virtual approaches as observed anecdotally by tertiary teaching practitioners; (5) The quality of learning will be very high compared to similar studies elsewhere as careful consideration was given by the tertiary educators to design a curriculum and learning outcomes that takes into account students' prior knowledge, their attitudinal preferences, learning styles and modes which provides for personalised, student-centred learning; (6) The Research will identify several strategies that will assist in improving students' learning outcomes even further and thus contribute to the cycle of continuous improvement of planning, implementing, valuating and reflecting of the teaching by the tertiary educators and a subsequent sharing of the insights gained to contribute to the knowledge base in the field and specifically the scholarship on teaching and learning related to signature pedagogies as well as the articulation of it in an emerging discipline like science communication.

4 Method

This study was carried out in the first half of 2011 with a cohort of undergraduates enrolled in a Bachelor of Science Degree at an Australian University in Victoria. Students were asked to produce digitally created knowledge maps but were given the freedom to choose from a range of software such as (for example CAM editor, Creately Compendium, Free mind, Freeplane, Inspiration, LucidChart, Sciplore, Mindmapping, Topicscape, Qiqqa, WikkaWiki, VUE, XMind).

The advantage of digitally created knowledge maps was summarised by Ng and Hanewald (2010) as flexibility to afford easy creation and infinite revisions as understanding of the topic increases in combination with the non-linear structure of hypertexts and its ability to include audio, video, still images as well various colours, sizes and fonts for the text, the nodes, their content, the vectors and linking words.

The use of c-map tool (http://cmap.ihmc.us/) was recommended to students as the preferred mode for the creation of their collaborative knowledge maps by the university teaching staff. The collaboratively produced digital knowledge maps were a part of the assessment for the students enrolled in EES101 Science Communication. Maps were produced in freestyle, which is according to Dansereau (2005) maps generated without any constraints or support. Another type would be a guided map, which are user generated maps with some sort of scaffolding such as predefined nodes or concepts. This approach is often used with novices, who have no prior experience in knowledge mapping. As the undergraduates were assumed to have extensive knowledge mapping experience due to the secondary school curriculum that implies this, the freestyle approach was seen as more suitable.

4.1 Participants

The Science Communication unit had a total of 118 enrolled students in the beginning of 2011, with 93 undergraduates volunteering to participate in the study. Of those, 60 students were attending the larger, metropolitan campus and 33 students were at the smaller, rural campus of the same university in Victoria, Australia. The majority of students are local, with some international students. The distribution of female and male students is fairly even, with most students being aged in their early twenties. All students were enrolled in EES101 Science Communication, which is a mandatory unit for the Bachelor of Science degree. There were five academics involved in the giving of the weekly lectures and accompanying tutorials.

4.2 Design

The data collection consisted of an eight question paper-based survey with multiple choice questions and 5-point Likert scales that were administered at the end of the course. This allowed for the accumulation of large data sets to establish students' prior knowledge of and experience with knowledge maps, their group working processes, the development of specific skills and their perception of the learning outcomes which they had achieved during the unit. A small number of individual students volunteered for semi-structured interviews which were audio recorded, transcribed and analysed. These conversations with a number of open-ended questions allowed for a more in-depth probing to elicit additional information on the process of creating the maps, the content knowledge that students had gained and the development of other skills (e.g. solving, creative thinking, communicating effectively, critical analysis). They also added a qualitative component to the gathered quantitative data from the surveys. The actual knowledge maps were produced in small groups of three to four students. The students had self-selected their team members and were able to choose the specific topic of their knowledge maps from a range of topics. Knowledge maps were collected twice: in their initial form and in their version. This allowed for tracking of the learning progress over the course of the unit of work. There was observable change and development in students' thinking and conceptual understanding over the 8-week period that the students worked on their maps (from the time the assessment was given to the due date). The three different instruments were used to enable triangulation, with data collected by an independent researcher.

4.3 Procedure

At the beginning of the academic year students were recruited on a volunteer basis and their informed consent for the research was obtained. The surveys were distributed in the first week of teaching. The knowledge maps were collected in their first (at the beginning of the unit) and final stage (at the end of the unit), which gave students a period of 8 weeks to work on the maps. After the completion of the course, volunteering students were individually interviewed by an independent researcher, who was not involved in the teaching of the students or the marking/grading of the students' work. This assured impartiality as the independent researcher had no vested interest in either of the two campuses, or any of the five tutorials and associated academic staff or any of the students. Anonymity of the student ensured, that they did not have to fear any repercussions from academic teaching staff for the remainder of their time at the university.

5 Automated Knowledge Map Analysis

Several methodologies for the automated analysis of knowledge maps have been introduced (e.g. Al-Diban & Ifenthaler, 2011; Hilbert & Renkl, 2008; Ifenthaler, 2010a; Johnson, Ifenthaler, Pirnay-Dummer, & Spector, 2009; Jonassen & Cho, 2008; Taricani & Clariana, 2006). They capture key latent variables associated with human learning and cognition. However, the reliability and validity of the computer-based and automated methodologies are often neglected. Still, AKOVIA (Automated Knowledge Visualization and Assessment) does include seven measures for automatically analysing knowledge maps and has been successfully tested for reliability and validity (Ifenthaler & Pirnay-Dummer, 2013).

AKOVIA uses specific comparison algorithms to calculate similarities between a given set of properties. Additionally, measures based on graph-theory are calculated for in-depth structural analysis of the knowledge maps (Ifenthaler, 2010b). Table 10.1 describe appropriate structural measures including information on its (a) operationalization, (b) computation rules and (c) diagnostic purpose. However, none of the structural measures account for the content of the underlying knowledge representation. A full list of graph-based measures can be found in Ifenthaler (2010b).

Table 10.1 AKOVIA graph-based measures (Ifenthaler, 2010b)

	(a) Operationalisation	(b) Computation rules	(c) Diagnostic purpose
Concepts	The size of the knowledge map is indicated by the sum of all embedded concepts	Computed as the sum of all vertices within a knowledge map. Defined as a value between 0 (no vertices) and *N*	Identify variations of vertices (e.g. between groups or track its change over time)
Diameter	The diameter of a knowledge map is a reliable indicator for the complexity	Computed as the quantity of edges of the shortest path between the most distant vertices (diameter) of the spanning tree of a knowledge map. Defined as a value between 0 (no edges) and *N*	The diagnostic purpose is to identify how broad the understanding of the underlying subject matter is

Additionally, AKOVIA produces standardised graphical re-representation of the participant's data as an undirected or directed graph with named nodes and links. This automated feature is realised with the help of the open source graph visualisation software *GraphViz* (Ellson, Gansner, Koutsofios, North, & Woodhull, 2003). For every single analysis, standardised *PNG* (Portable Network Graphics) images are generated (Ifenthaler, 2010a; Ifenthaler & Pirnay-Dummer, 2013).

6 Results and Discussion

6.1 Survey Questions

Figure 10.1 shows the students ($N=93$) prior experience in using knowledge maps according to curriculum key area, which are as follows in the secondary school curriculum of the state: The Arts, English, the Humanities, LOTE (Languages Other than English), Mathematics and Science. The rural cohort ($N=33$) and the metropolitan cohort ($N=60$) both indicate Science and English as the curriculum areas in which they were exposed to knowledge maps. The Arts, Maths and LOTE were equally poorly represented and a small group of students (3 at the rural campus and 7 at the metropolitan campus) had never used a knowledge map. It is worth noting that students were allowed to circle all curriculum areas that applied, hence multiple answers were given.

As outlined in the introduction, academics are assuming a high degree of familiarity with digital knowledge mapping in first year undergraduate students due to the Australian Curriculum in secondary schools, which implies teaching of this technique across key learning areas. Hence, the tertiary learning activities and

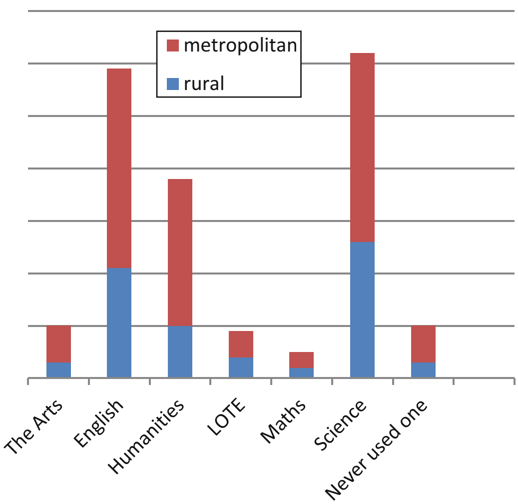

Fig. 10.1 Before this unit in what discipline have you used knowledge maps?

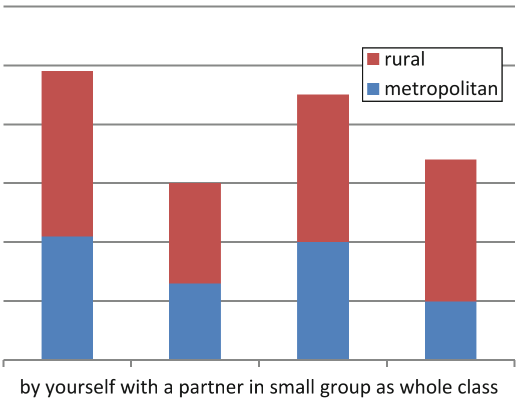

Fig. 10.2 Before this unit did you make a knowledge map?

teaching pace is pitched at an advanced level of knowledge in regard to digital knowledge maps. However, the first question in the survey indicated that more than 10 % (10 students out of 93; specifically 3 out of 33 students on the rural and 7 out of 60 on the metro campus) had never used a knowledge map. The results for Mathematics were the lowest with only 5 students out of 93 using knowledge maps in that key learning area. The Arts (10 student out of 93) and LOTE (9 students out of 93) showed around 10 % of knowledge map usage. Almost two thirds of the students had used knowledge maps (59 out of 93) in the key learning areas of English and Science (62 out of 93).

The results from Question 2 generated by the administered survey are displayed in Fig. 10.2, which shows that individually constructed knowledge maps (49 out of 93 students) and those constructed in small groups (46 out of 93) were 60 % of the employed working mode. Knowledge maps constructed with the whole class (34 out of 93 students) and with a partner (30 out of 93) have only been practised by a third of the students. These findings seem to indicate a preference for individual work although it cannot be established whether this mode of learning was freely chosen by the learners or set by the classroom teacher at the time. However, it can be confidently set that students had the most prior experience of working with knowledge maps in secondary schools by doing so either individually or in a small group.

Figure 10.3 shows the students' prior experience of creating knowledge maps either manually (drawn by hand) or electronically (with a computer). Maps designed with pen and paper approach (30 out of 33 rural students and 48 out of 60 metropolitan students) outweighed those created on a computer (only 9 out of 33 rural students and 20 out of 60 metropolitan students). Again, while this is no clear indication of the students' preferences due to the lack of information related to either it being their choice or the direction by their secondary school teachers, it can be deducted that this is the students' prior experience.

As mentioned, students' were given the freedom of choice in terms of how to produce their knowledge map. Academic staff strongly recommended using Cmap tools as this was one of the assessment tasks within one of the units for the Bachelor of Science degree. Figure 10.4 shows the students' overwhelming preference for pen

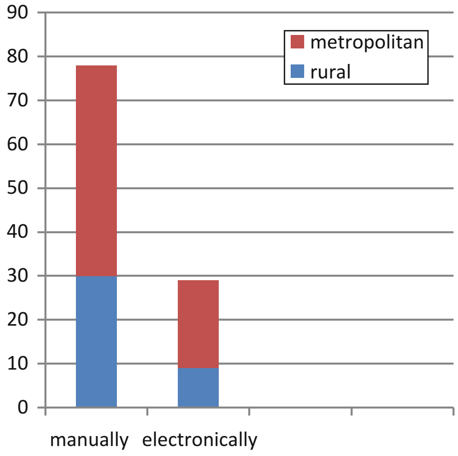

Fig. 10.3 Before this unit was the knowledge map made with paper and pen (by hand) or with a computer (electronically)?

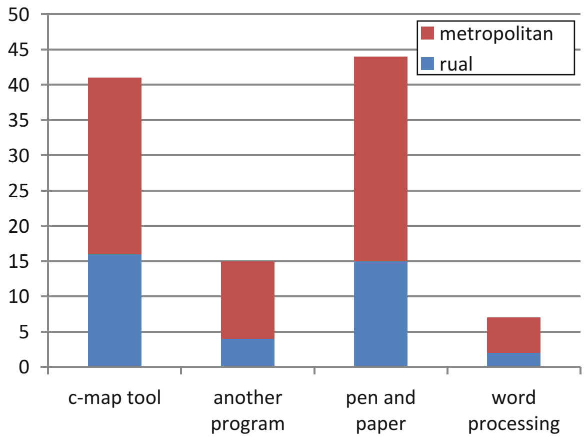

Fig. 10.4 In producing your knowledge map for this unit did you c-map tool, another knowledge mapping program, pen and paper or a drawing or word processing program?

and paper (44 out of 93) with nearly half of the students opting for hand drawn knowledge maps. This preference was observable across the rural campus (15 students out of 33) and the metropolitan campus (29 out of 60). These findings are linked the tension between the anecdotal evidence gathered by academics teaching this unit in previous years and the existing body of literature. Vignettes by lecturers at this Australian university consistently showed that undergraduate students—part of the Net Generation and also called Millennials—had very low technology skills. It seemed to be limited to basic communication and information skills such as emails, SMS, Social Networking Sites (SNS), blogs or microblogs (for example Twitter) videoconferencing (Skype), and the use of search engines (e.g. Google, Yahoo). SNS such as Facebook, MySpace, Xing or Yammar and even (micro)blogs use template style applications such as pre-fabricated user profiles that need only filling with content, thus being quick and easy to use, intuitive and user-friendly as they require little technology skills and time to achieve a polished looking online presence.

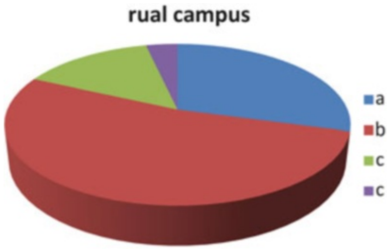

Fig. 10.5 Results for students on the rural campus working in teams using various approaches for creating their knowledge maps

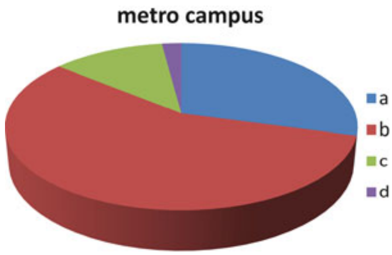

Fig. 10.6 Results for students on the metropolitan campus working in teams using various approaches for creating their knowledge maps

This observed level of rather low technology skills in students by university teaching staff was in stark contrast to the portrayal of techno savvy Net Gen or Millennials in the relevant literature. This chasm between the assumed skills, knowledge and attitudes as depicted in the literature and the actual skills, knowledge and attitudes of the Millennials had caused significant tension. Undergraduate courses and thus the curriculum, learning activities and outcomes were pitched to a level of teaching that presupposed technological sophistication of the Net Generation prior to entering university.

Survey question 4 also revealed that Cmap tools (recommended by university staff) was used by 41 students out of 93 (16 at the rural and 25 at the metropolitan campus) while 15 (out of 93) students (4 at the rural and 11 at the metro campus) used another computer program. A drawing or word processing program was used by 7 (out of 93) students (3 at the rural and 5 at the metro campus).

Question 5 of the survey tried to answer point 3 in the introduction and illuminate students' ways of working in a group. It asked students whether all group members added physically to the knowledge map (a), whether all group members contributed orally to the content but had one person who physically drew the map (b), whether one person drew the map and the other group members amended it (c) or whether it was solely one person's responsibility (d) (Figs. 10.5 and 10.6).

It was most surprising that—despite the students of both campuses having no contact with each other due to the geographic distance—they used identical approaches and had the same preferences for constructing their knowledge maps within their team. The preferred way of working was for one person taking on the responsibility of drawing the map with other team members verbally feeding their thoughts in terms of key concepts, relationships between concepts and hierarchies of concepts into the collaborative construction. On both campuses, more than half

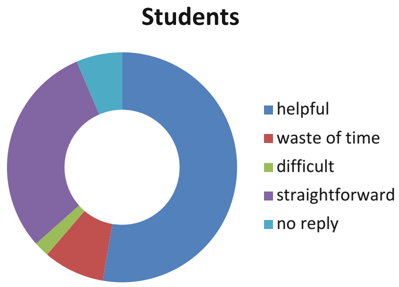

Fig. 10.7 Students' experience on doing the knowledge map for this unit

of the student cohort (18 out of 33 on the rural campus, 33 out of 60 on the metro campus) chose that option. Less than a third of students on both campuses (10 out of 33 on the rural and 17 out of 60 on the metro campus) constructed their knowledge map in a way that all team members contributed physically to the map. On both campuses, there were teams where one person drew the map and the rest of the team amended it. This was the case for 12 students out of 93 overall (5 out of 33 on the rural and 7 out of 60 on the metro campus). A total of 8 students (out of 93) indicated that the responsibility of producing the map was left to 1 person (2 out of 33 students on the rural and 7 out of 60 students on the metro campus). This is somewhat surprising given the importance of this task as the knowledge map was an assignment and as such part of the students' grade (final mark) for the unit. It also has to be kept in mind that the numbers for the last case are actually much higher, as are the real numbers for all of these values. The findings are based on only 93 students who gave their permission and participated in this study and not the actual 118 students who were enrolled in the course. The difference of the 25 students' input (who opted not to participate in the research) could have shed much greater light on the situation.

Figure 10.7 displays the results in response to research question 5, how students rate the experience of doing a knowledge map. More than half (53 %) of the students on both campuses (49 out of 93 students; 23 out of 33 on the rural and 26 out of 60 on the metro campus) declared that the experience of doing maps helped them think about their topic. Less than 10 % (9 out of 93 students; 2 on the rural and 6 on the metro campus) thought that doing knowledge maps was a waste of time. While 1 student on each campus (total 2 out of 93) thought it to be difficult and frustrating, almost a third of students (28 out of 93; 7 on the rural and 21 on the metro campus) thought it to be straightforward. However, it is not clear whether this assessment related to the actual process of designing a knowledge map, the necessary content knowledge or the ability to identify key concepts, their relationships and their hierarchies. A total of 6 students (out of 93) gave no reply.

It should be noted here that the last two questions in particular (Question 4 and 5 of the survey) were investigated in much more depth during the individual interviews with students. It revealed the reasons for those preferences, which were mostly based on time pressures and a desire for efficiency in accomplishing the task rather than

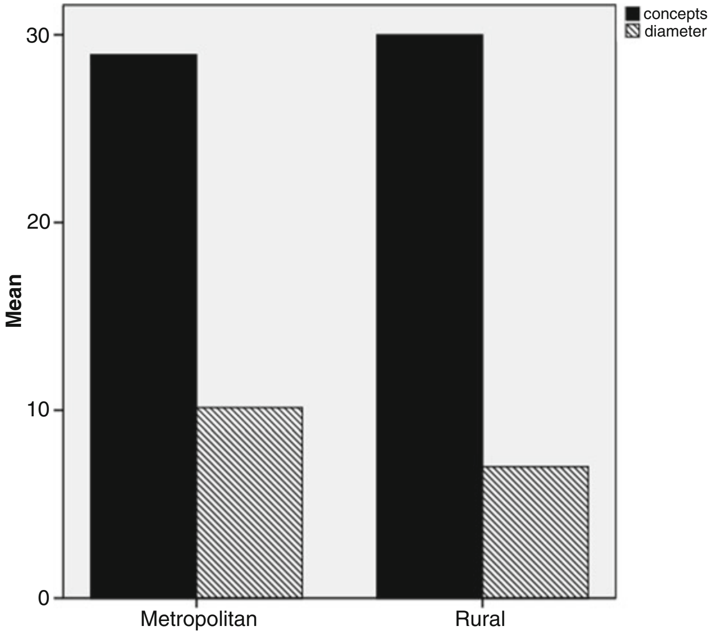

Fig. 10.8 AKOVIA structural measures separated by metropolitan and rural group

gaining maximum learning benefit from it. However, this chapter will focus only on the surveys and analysis of the actual maps only and has thus deliberately omitted verbatim quote from and abstained from discussions of the interviews.

6.2 AKOVIA Analysis

Given the survey results, a post-hoc analysis of constructed knowledge maps was realised. However, not all knowledge map data was available and it was not able to link the knowledge map data with the survey data due to institutional restrictions.

Still, 28 knowledge maps were analysed with AKOVIA. Of those, 15 knowledge maps were created by participants from the metropolitan area and 13 knowledge maps were created by participants from rural areas. Figure 10.8 shows the concepts and diameter measure separated for the metropolitan and rural participants. Two independent-samples *t*-Tests were conducted to compare *concepts* and *diameter* measures in *metropolitan* and *rural* conditions. There was a significant difference in the diameter measure for metropolitan ($M = 10.13$, $SD = 4.63$) and rural ($M = 7.00$,

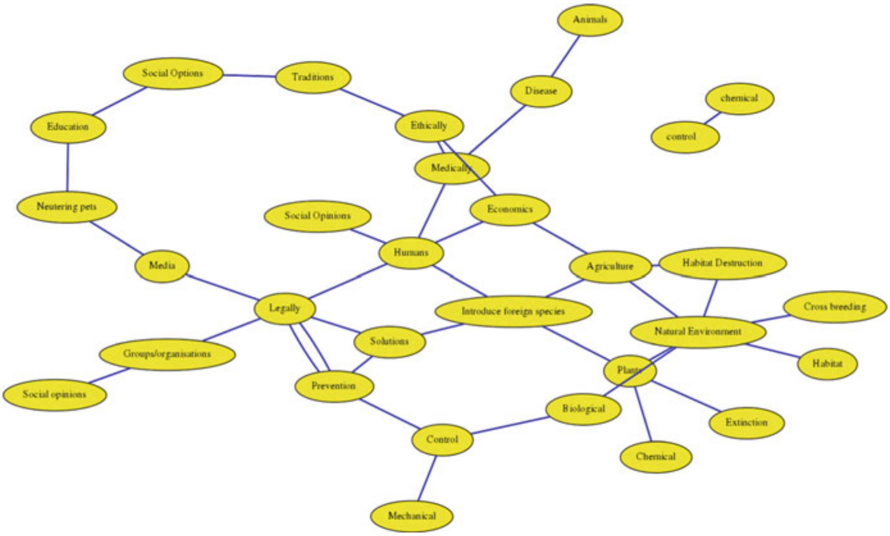

Fig. 10.9 AKOVIA re-representation of metropolitan participant

SD = 1.29) conditions, *t*(26) = 2.358, *p* = 0.026, *d* = 0.921. No significant difference were found between the metropolitan (*M* = 28.93, *SD* = 12.65) and rural (*M* = 30.00, *SD* = 14.47) conditions for the concepts measure, *t*(26) = 0.208, *p* = n.s.

Figure 10.9 shows an automated re-representation of a knowledge map constructed by a metropolitan participant. The knowledge map integrates complex cyclic processes which is representative for all participants of the metropolitan cohort.

This also reflects the significant difference in the diameter of the knowledge maps which identifies the complexity of the participants' representations.

Figure 10.10 shows an automated re-representation of a knowledge map constructed by a rural participant. The knowledge map is less complex, i.e. reflects a linear structure.

Both, the quantitative analysis of AKOVIA measures and qualitative analysis of automatically generated graphical re-representations provide meaningful insights into the quality of knowledge maps.

Moreover, AKOVIA allows us to produce instant feedback on semantic and structural aspects of the learner's learning progression at all times during the learning process. Such dynamic and timely feedback can promote the learner's self-regulated learning (Ifenthaler, 2011; Zimmerman & Schunk, 2001). Recently, two intelligent and automated model-based feedback tools have been developed and implemented: (1) TASA (*T*ext-Guided *A*utomated *S*elf *A*ssessment), which generates automated feedback to learners based on natural language text input (Ifenthaler, 2011; Pirnay-Dummer & Ifenthaler, 2011). (2) iGRAF (*I*nstant *G*raphical *F*eedback), which automatically generates graphical representations based on the prior knowledge of the learner (Ifenthaler, 2009, 2011).

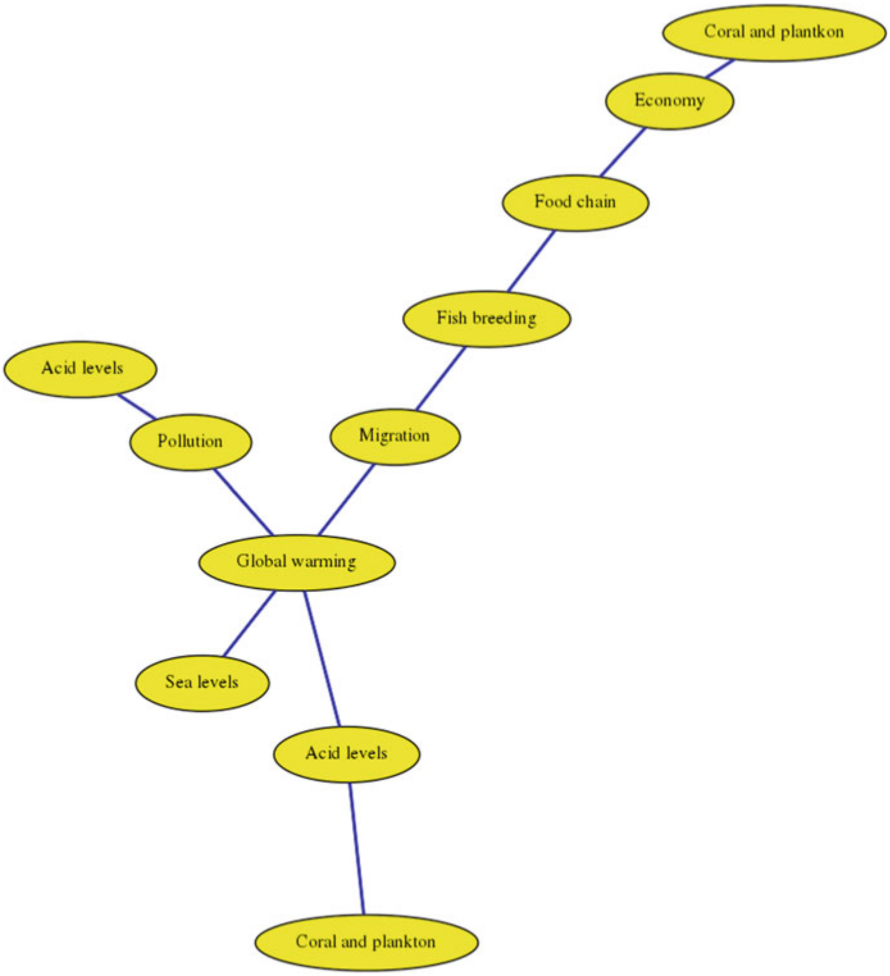

Fig. 10.10 AKOVIA re-representation of rural participant

7 Conclusion and Recommendations

Given the literature and reports in the mass media, students studying at either at a rural or metropolitan campus might be concerned that they are receiving a lesser standard of quality in terms of the teaching and learning programmes on offer. The results from this study indicate that students with similar levels of pre-existing knowledge will gain similar learning outcomes, regardless of the location of the campus provided it is with the same university.

One of the disappointing findings of the study was that students entering higher education settings have limited experience with knowledge mapping and only a third of students had made a knowledge map on a computer, which seem to indicate little use of technology in secondary schools despite the technology rich school system. Concerning was the finding that more than 10 % of undergraduates (10 students out of 93) had never used a knowledge map as part of their formal education, which covers a period of 12 years. However, as there were a small proportion of international students enrolled in this course, it is hoped that those answers stem from that part of the cohort and are not a reflection on the quality of Australian secondary school education. An indication on the survey to show whether the person answering is a "local" or "international" student would clarify this aspect. However, it would be difficult to have this question approved by the University's Research on Humans Ethics Committee as it is violating their guidelines for the collection of data.

Surprising was the admission of eight students that they abdicated the creation of the knowledge map to one team member while being fully aware that they would be assessed on the work and this grade would count towards their final mark for the unit. The actual number of students that are not contributing to a task but are graded on it is probably higher given that a fifth of the student cohort did not agree to be involved in the research. This is a limitation of the research, which could be overcome by mandatory participation to ensure complete and larger data sets. However, this would violate University's Research on Human Ethics guidelines and is therefore not possible.

Question 4 and 7 showed a preference for manually created knowledge maps in favour of digital knowledge maps and students complaining about knowledge maps being difficult, frustrating and a waste of time, which seems to indicate a lack of interest or proficiency in technology-based learning. Testing Net Gen students' technology skills prior to university entry would give reliable data about the level of their abilities and establish if these "digital natives" are as techno savvy as assumed.

This study was set up as a first in a series of 3, with the view of refining questions and gathering more detailed information in progressive years. The main limitations of the study are in the small sample and the restrictions set by the University's Research on Humans Ethics Committee. However, it is hope that some insights have been gained from this endeavour.

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Chapter 11
Using Novakian Concept Maps to Foster Peer Collaboration in Higher Education

Paulo Correia, Camila Cicuto, and Joana Aguiar

Abstract Novakian Concept maps (N-Cmaps) and the hierarchical reductionism method are combined to create a new pedagogic architecture to address high-complexity issues in classrooms. This strategy considers the epistemological challenge of managing a substantial amount of information from diverse disciplinary fields and the need to engage students in productive, collaborative work sessions to generate the synergistic effect of combining many informed individuals' perspectives. Discussions through peer collaboration can be organised to achieve the creation of a knowledge model (KW), i.e. a hypertext structure containing a collection of N-Cmaps with any digital resources about the field under study. Students create their own hypertext and use it as visual resource of information to navigate through the complexity they are learning. After discussing the theoretical foundations that underlie our instructional design, we present a case study involving the collaborative creation of a KM to characterise the interdisciplinary connections among six undergraduate courses offered at the School of Arts, Sciences and Humanities (University of São Paulo, Brazil). Fifty-two students worked collaboratively to map the connections among these courses and the results revealed an interesting perspective. The structured approach adopted to organise the collaborative knowledge construction process allowed students to make explicit several latent information about the courses they were enrolled. The possibility of reducing cognitive overload explains why the combination of N-Cmaps and the hierarchical reductionism method is useful to grasp complexity in classrooms.

Keywords Complexity • Hierarchical reductionism • Hypertexts • Knowledge models • Novakian concept maps • Peer collaboration

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1 Addressing Complex Issues Using Hierarchical Reductionism and Collaborative Learning

Our contemporary society can be understood in the context of the following three critical events that occurred during the late twentieth century: the knowledge explosion, information technology development and globalisation. These events collapsed the old industrial society in less than 50 years and created a new, flat world in which we are all tightly connected (Friedman, 2007; Hobsbawn, 1996). Time and space acquired new meanings for citizens of knowledge societies, who must address problems with a new level of complexity. "*Problematiques*" were proposed by the Club of Rome as a means of conceptualising these types of highly complex problems with long-term global impacts (Club of Rome, 1970). Environmental deterioration, poverty, endemic sickness, urban blight and criminality are some examples of "*problematiques*" that are virtually impossible to understand and solve in isolation.

These societal changes rendered the old-fashioned educational paradigms obsolete. They were devised to address the demands posed by an industrial society. The need to develop new pedagogic architectures is only the long-awaited response to the new challenges presented by our contemporary society (Robinson, 2001; Sawyer, 2006; UNESCO, 2005). New roles for instructors and students must be considered, as well as the time and space in which education occurs. Meaningful, collaborative, self-regulated and lifelong learning must be pursued throughout formal education to prepare individuals to be autonomous citizens in the twenty-first century (Visser & Visser-Valfrey, 2008).

Real-world problems are highly complex, and addressing them in the classroom is challenging for many reasons. However, instructional strategies must be devised to include such issues into our teaching routines because contemplating their complexity allows students to develop high-order thinking skills, such as problem solving, team work and creative thinking. Moreover, real-world discussions place disciplinary content into a broad and meaningful framework, facilitating the application of scholarly knowledge in real-world situations. Our experience has revealed the following primary obstacles to the discussion of complex issues in higher education: the epistemological challenge of managing a substantial amount of information from diverse disciplinary fields and the need to engage students in productive, collaborative work sessions to generate the synergistic effect of combining many informed individuals' perspectives. This chapter presents a solution based on the use of Novakian Concept maps (N-Cmaps) to develop Knowledge Models (KMs), which allows the organisation of information and knowledge using the hierarchical reductionism approach proposed by Dawkins (1996).

Complexity can easily lead to cognitive overload due to the amount and diversity of information we need to process. This issue is particularly problematic for people who are accustomed to contending with well-formatted disciplinary questions. This epistemological challenge can be confronted using the hierarchical reductionism approach, which is a safe way to produce good answers to complex problems

(Dawkins, 1996). The main idea is to describe complex systems using a hierarchy of organisations, each of which is only described in terms of objects (concepts) one level down in the hierarchy. This strategy ensures that all explanations about the system are generated by a step-by-step approach and contain a manageable number of elements (concepts) to be processed. In this context, it is easy to make self-judgments about the need to delve deeper into explanations about specific parts of the system without losing the broader view of it. Systemic thinking is strengthened because it is possible to continuously connect the parts with the whole system. In summary, hierarchical reductionism offers an interesting way to organise information and knowledge in the study of complex issues (e.g. *problematiques*) in higher education.

Graphic organisers are powerful tools for representing information and knowledge that can boost the hierarchical reductionism approach. These organisers can make all resources consistently visible to all the people who need to contend with a given complex problem, fostering collaboration through discussions from the same starting point. Each participant can present his or her particular perspectives and change the shared visual representation in real time. Beyond being user friendly, graphic organisers can foster collaborative learning when they are used in accordance with the theories that underlie their development. Of the several types of node-link diagrams, the concept mapping technique developed by Joseph Novak has been our preferred choice to represent conceptual and propositional knowledge. The following section discusses our choice and the use of N-Cmaps to build Knowledge Models (KMs) that foster the use of the hierarchical reductionism approach.

1.1 Novakian Concept Maps and Knowledge Models

Concept mapping is a well-established technique for the graphical representation of information and knowledge, which enables the explicit description of mental models. Since its introduction in 1972, N-Cmaps have often been used for educational and corporate purposes and have changed the way we manage knowledge and information (Hoffman, Coffey, Ford, & Novak, 2006; Moon, Hoffman, Novak, & Cañas, 2011; Nesbit & Adesope, 2006; Novak, 2010). The benefits of using N-Cmaps to represent and share our ideas depends on one's skills as a mapper and the understanding that such maps are more than simple diagrams or charts (Correia, 2012; Davies, 2011). When these conditions are met, concept mapping is likely to promote changes in teaching, learning and assessing students (Novak, 2002, 2005).

Propositions are the remarkable feature of N-Cmaps. They are formed by two concepts connected by a linking phrase (Fig. 11.1a) that clearly states their conceptual relationship. The absence of a linking phrase hinders the understanding of the conceptual relationship (Fig. 11.1b), producing associative node-link diagrams, such as mind maps (Davies, 2011). The lack of accuracy impairs the process of clarifying the mental model and, importantly, the communication of one's own ideas. This situation is the same when the linking phrases do not contain verbs (Fig. 11.1c), because no statements are formulated yet. However, slight changes in linking phrase

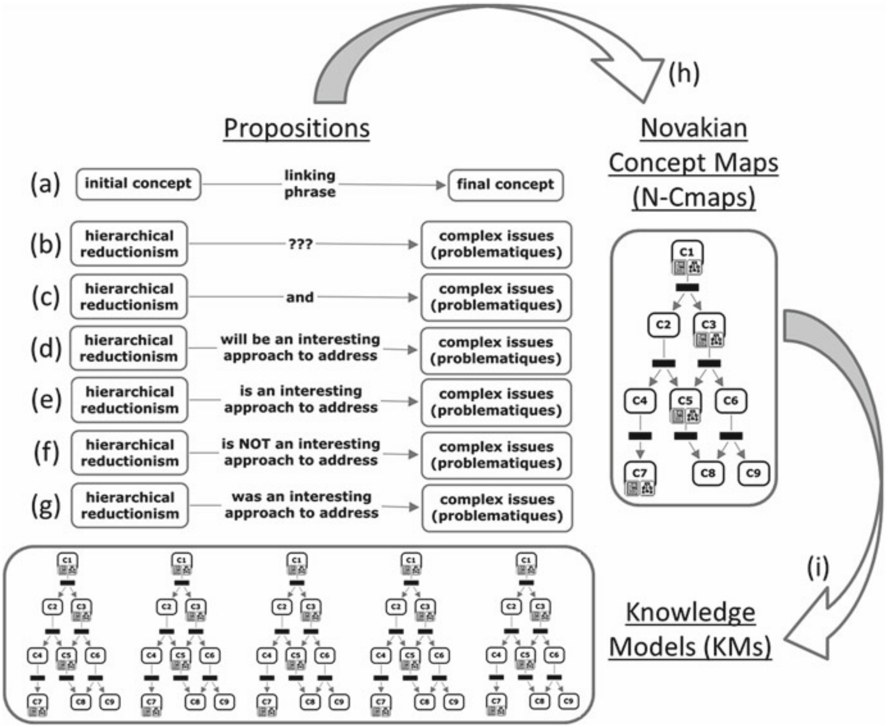

Fig. 11.1 The general structure of propositions (**a**), some examples (**b**–**f**) and the structural relationship between propositions/N-Cmaps/KMs (**h**–**i**)

words dramatically change the meaning of the statement when the linking phrases are presented with verbs. For example, we can consider that we are reading this chapter before Dawkins devised hierarchical reductionism (Fig. 11.1d), at the present (Fig. 11.1e precisely expresses the authors' beliefs), and in the future (Fig. 11.1g supposes that something better than "hierarchical reductionism" will be invented). Interestingly, Fig. 11.1f shows the power of a one-word transformation of a statement with the addition of "not". This set of propositions does more than highlight the critical role of linking phrases to the clear expression of one's ideas: it shows the fine-tuning adjustments the mappers can make to determine the best way to externalise and communicate their thoughts. Finally, Fig. 11.1 explores the hierarchical reductionism nature of propositions, N-Cmaps and KMs: they can always be described structurally in terms of objects one level down in the hierarchy. Propositions are the building blocks of N-Cmaps (Fig. 11.1h), and N-Cmaps are the building blocks of KMs (Fig. 11.1i).

For many years, N-Cmaps were drawn by hand. Creating iterative revisions of an N-Cmap was cumbersome and time-consuming. Group concept mapping sessions could be facilitated using post-it notes. The possibility of exploring concept mapping online launched a completely new world of applications and uses for concept

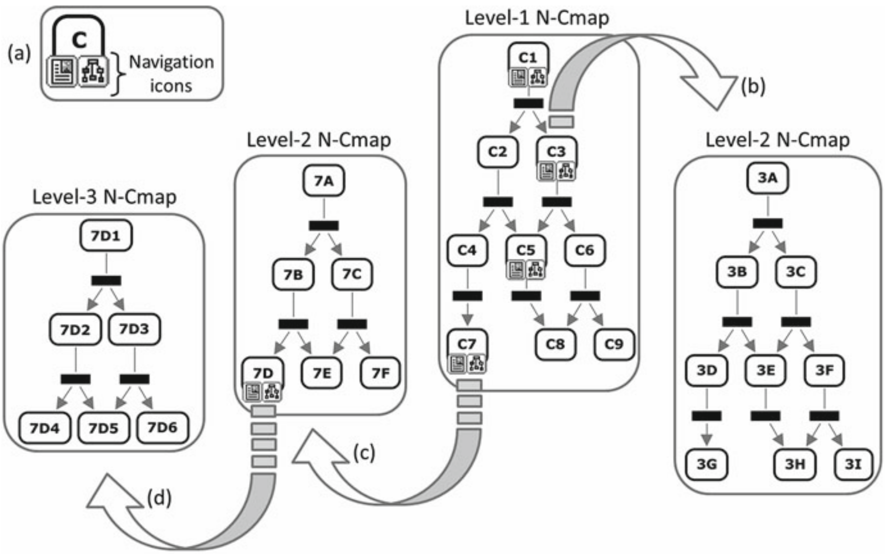

Fig. 11.2 Schematic representation of KM containing 4N-Cmaps and three hierarchical levels

mapping as exemplified by the CmapTools software, which was developed by the Institute for Human and Machine Cognition (Cañas et al., 2004). Undoubtedly, CmapTools have enhanced the power and applicability of N-Cmaps in educational and corporate settings (Moon et al. 2011; Novak, 2010).

The digital concept mapping approach using CmapTools allows the creation of more than isolated N-Cmaps. The concept of Knowledge Models (KMs) leverage the possibility of mapping information and organising knowledge by constructing a set of hyperlinked N-Cmaps that include any associated resources (any digital file can be linked to any concept) about a particular domain (Fig. 11.2). The resultant hypertext structure is similar to a web site and is user friendly even for first-time users. KMs can be explored by navigation links that appear below the N-Cmap concepts (Fig. 11.2a).

The KM is a well-structured environment that can be constructed by students when they are learning about complex issues (e.g. *problematiques*). KMs allow the implementation of the hierarchical reductionism approach when students are faced with a huge amount of information. The organisation of all of the N-Cmaps they make can follow the hierarchical pattern presented in Fig. 11.2, using the concepts of a broad view N-Cmap as starting point to make more focused N-Cmaps. The Level-1 N-Cmap illustrates a broader view about the topic, and concepts C3 and C7 are critical to capturing all of the complexity involved. These concepts are detailed in the Level-2 N-Cmaps (Fig. 11.2b–c), preserving the overall KM organisation. This rationale can be further explored to create Level-3 N-Cmaps (Fig. 11.2c) followed by however many other levels the students deem to be necessary to describe the topic. The dynamic nature of collaborative learning and concept mapping make revision a constant throughout this process, and the hierarchical organisation of KM allows students to keep improving it without losing systemic thinking.

The aim of this chapter is to discuss the theoretical framework underlying the use of KMs to foster peer collaboration in higher education and to present a case study involving the attempt of first year undergraduate students to characterise the interdisciplinary connections among six undergraduate courses offered at the School of Arts, Sciences and Humanities (University of São Paulo, Brazil).

2 Collaborative Learning Using Novakian Concept Maps: Theoretical Considerations

One of the challenges of including interdisciplinary and complex problems in any course syllabus is the need to use a rarely explored pallet of teaching methods, which must be orchestrated to create a rich peer collaborative environment (Dillenbourg & Jermann, 2010). As noted by Mayer (2010), the instructional design should be guided by a research-based theory of how instruction affects learning. Cognitive Load Theory has been an attempt to link instructional demands and learning outcomes through consideration of how we manage our restricted short-term memory resources (Sweller, Ayres, & Kalyuga, 2011). Its general advice is to minimise the extrinsic cognitive load (caused by the way the instructional material and the activities are presented) to make more cognitive resources available to deal with the instructional material itself and to develop schemas (known as the intrinsic and germane cognitive loads, respectively). The current discussions about Cognitive Load Theory limitations confirm that it is still evolving and attracting the interest of many researchers around the world (de Jong, 2010). In particular, the need to establish strong theoretical foundations to encourage progress in research to develop robust instructional activities that work under real-world conditions seems clear.

The theoretical framework that guides the use of KMs to foster peer collaboration is presented in Fig. 11.3. Our broad assumption is that visualisation tools support collaborative knowledge construction (Fischer, Bruhn, Grasel, & Mandl, 2002; Vekiri, 2002). These tools allow participants to visualise, discuss and model information throughout the collaborative process, making it possible to organise the discussion of complex issues using the hierarchical reductionism method proposed by Dawkins (1996). Paivio's Dual Coding Theory describes how node-link diagrams can optimise the use of short-term memory resources by allowing the simultaneous processing of imagery and language information without causing cognitive overload (Paivio, 1990).

Among the other options, such as mind maps and argument maps, N-Cmaps seem to be the best choice to reveal conceptual relationships due to the need to express meaning through propositions (Correia, 2012; Davies, 2011). Moreover, N-Cmaps have a decades-long background of research and application, dating back to the 1970s, when the notion of concept mapping was first developed by Joseph

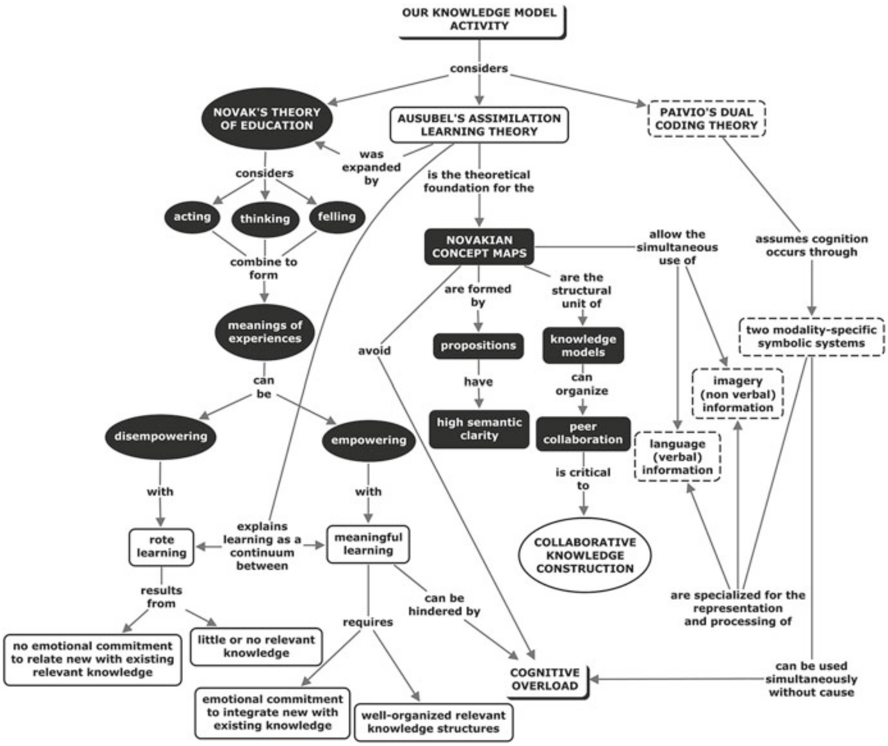

Fig. 11.3 What is the theoretical framework guiding the use of N-Cmaps to foster peer collaboration?

Novak and his colleagues at Cornell University (Moon et al., 2011; Novak, 2010). Finally, the N-Cmaps have strong connections with Ausubel's Assimilation Learning Theory, creating a sound body of theoretical knowledge regarding their use.

Our broad educational perspective is aligned with Novak's Theory of Education, which includes a humanistic view of the cognitive perspective developed by Ausubel. Collaborative activities are critical to sharing the meaning of experiences through student–student and instructor–student interactions. Meaningful learning is likely to occur in this meaning-making environment, when the instructor provides a scaffold for the students during the learning process. Beyond the taught content, empowering experiences should be considered the ultimate goal of the educational enterprise. Empowered students will be open to developing self-regulated and life-long learning skills, which are part of the formative demands posed by our contemporary society (UNESCO, 2005; Visser & Visser-Valfrey, 2008). We believe that the use of N-Cmaps and KMs to foster peer collaboration is an empowering experience that can be explored in higher education.

2.1 Theoretical Accounts of Learning and Education

Ausubel's Assimilation Theory of Meaningful Learning and Retention refers to the description of the learning process on a continuum between two extremes, called meaningful and rote learning (Ausubel, 2000; Mayer, 2002). The distinction between them is characterised by how new information relates to the relevant aspects within the existing cognitive structure of each learner. In meaningful learning, relationships are established in non-arbitrary and non-literal ways; this process requires more cognitive effort to relate the individual's prior knowledge to the new information. However, these relationships are established arbitrarily and literally in rote learning and do not require the individual to check the effect of prior knowledge on the new information (Ausubel, 2000; Novak 2010). The following conditions are critical to fostering meaningful learning:

- Identify students' prior knowledge and plan teaching activities accordingly,
- Select instructional materials that are relatable to the students' prior knowledge, and
- Choose to learn meaningfully, which is the students' decision.

Meaningful learning is more demanding than rote learning, and it must be understood as a partnership involving both the instructor and students. It is necessary to establish a favourable learning atmosphere because the requirements for achieving meaningful learning ask for the commitment of both instructor and learners. The identification of students' prior knowledge involves the instructor (who devises an activity for this aim) and the students (who should participate and reveal their prior knowledge). The instructional material selection is the instructor's decision, whereas the choice to learn meaningfully is exclusively the students' decision.

A schematic comparison between meaningful and rote learning is presented in Fig. 11.4. Rote learning is characterised by arbitrary and literal relationships between prior knowledge (A) and new information (a). There is no cognitive effort to create meaning to relate them (Aa presents high dissociation levels). The new information is likely to be forgotten in a short time period, and it could be not used in a different context than that used during the learning process. In summary, we can state that rote learning does not change prior knowledge, and new information is isolated in the cognitive structure, making it difficult to remember and retrieve it.

Meaningful learning implies non-arbitrary and non-literal relationships between prior knowledge (A) and new information (a). The learner acts intentionally to create meaning between them, usually subsuming new information (a) from more inclusive concepts they already know (A). All of this cognitive effort transforms the prior knowledge by merging it with the new information. This process reduces "Aa" dissociation levels and produces a new composite (A'). This process is an economic means of storing new information in the cognitive structure, making it useful for contexts other than that used during the learning process and keeping it available for a long time. This type of learning outcome is likely to empower students throughout higher education and help them become ready to learn how to learn (Novak, 2010).

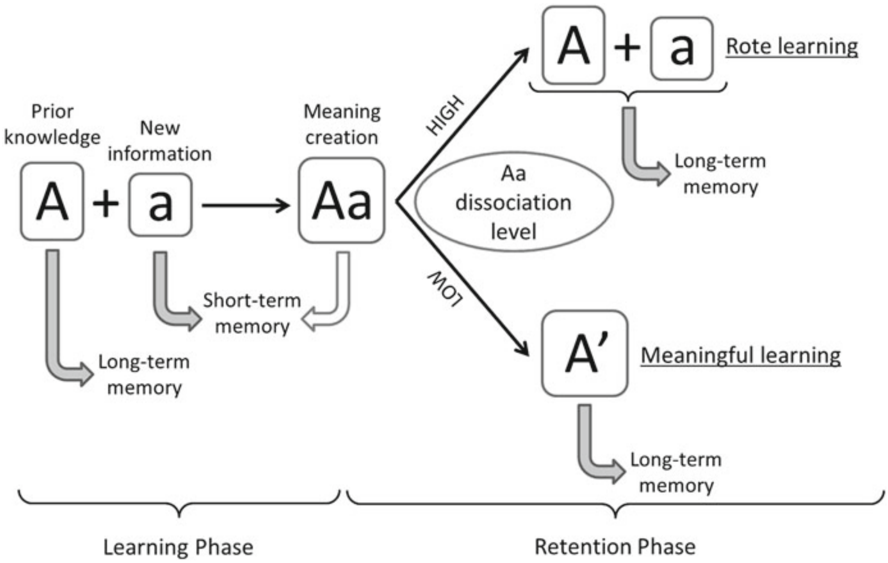

Fig. 11.4 Schematic comparison of the outcomes obtained by rote and meaningful learning after the retention phase, according to Ausubel's theory

Meaningful learning does not imply the absence of conceptual mistakes (Novak, 2002; Novak & Musonda, 1991). On the contrary, the literature refers to them as misconceptions, alternative conceptions, naive notions and pre-scientific notions. Novak (2002) proposed Limited or Inappropriate Propositional Hierarchies (LIPHs) to refer to these types of conceptual errors. The identification of LIPHs in N-Cmaps is straightforward, as the lack of semantic clarity of some propositions may reveal the presence of mistakes or limited understanding. For example, poorly chosen linking phrases constrain the accuracy of messages embedded in the propositional network. Novak (2002) proposed LIPHs as suitable starting points to foster meaningful learning. Therefore, instructors can also use N-Cmaps as a learning evaluation tool to identify LIPHs and to intentionally plan and revise upcoming learning activities to continue to foster meaningful learning (Cicuto & Correia, 2012).

Empowerment is an educational demand linked to the humanist perspective, and it complements the cognitivist repertoire frequently used to understand how we learn. The cognitive-humanist interface was well explored by Novak, who developed a Theory of Education from the cognitive ideas proposed by Ausubel. Beyond thinking, humans also engage in feeling and acting, and all these aspects must be combined for significant new learning to occur, especially in the creation of new knowledge (Novak, 2010). The educational challenge is to manage all three forms of learning, defined as follows: the acquisition of knowledge (cognitive learning), change in emotion or feelings (affective learning) and gain in physical or motor actions or performance (psychomotor learning). They combine to enhance a person's capacity to make sense of their experiences. In this context, Novak proposes the following broad definition of meaningful learning to address this cognitive-humanist interface, which is more connected to the formative demands posed by knowledge societies: "meaningful learning underlies the constructive integration of thinking, feeling and acting leading to empowerment for commitment and responsibility" (Novak, 2010: 18).

2.2 Collaborative Knowledge Construction as a Model for Peer Collaboration

Collaborative activities are important to allow social exchange during the learning process. Interactions in classrooms or e-learning environments can involve learners alone (peer collaboration) or the learners and the instructor. Vygostky's (1978) concept of the Zone of Proximal Development (ZPD) is useful to differentiate these interactions, because students are usually at approximately the same level of cognitive development on a given topic and may enhance one another's learning if they engage in an active exchange of ideas. This similarity is not observed during a learner–instructor interaction, because they are at different levels of cognitive development on a given topic.

Three different types of collaborative interactions can be identified during the learning process, when power asymmetry and ZPD similarity are considered as variables (Correia & Infante-Malachias, 2009). The vertical, horizontal and diagonal collaborations are schematically depicted in Fig. 11.5. Vertical collaboration occurs between instructor and students, where the former's task is usually to transmit knowledge, and the latter's task is to receive the transmitted knowledge. High power asymmetry and the difference between the teacher's and students' ZPD characterise this vertical collaboration. However, horizontal (peer) collaboration is observed when students interact with their counterparts. In this case, power asymmetry is minimised, and students are at approximately the same ZPD. Consequently, students who are at approximately the same level of cognitive development (same ZPD) on a given topic will enhance each one another's learning if they engage in an active exchange of ideas (Cañas & Novak, 2006; Vygostky, 1978).

Diagonal collaboration can be considered to be a hybrid situation of vertical and peer interactions. They expand the possibilities for planning collaborative activities considering different levels of participations for instructor and students, varying from an instructor-enriched (close to vertical collaboration) to a student-enriched diagonal collaboration (close to peer collaboration). These situations should be explored intentionally, considering theory-based research concerning computer-supported collaborative learning (Kollar, Fischer, & Hesse, 2006) and classroom orchestration (Dillenbourg & Jermann, 2010). The use of N-Cmaps and KMs we will show as case study to address complex issues in higher education was planned to be a student-enriched diagonal collaboration.

There are several ways to describe collaboration. Collaborative knowledge construction (CKC) proposed by Fischer et al. (2002) is our preferred choice because

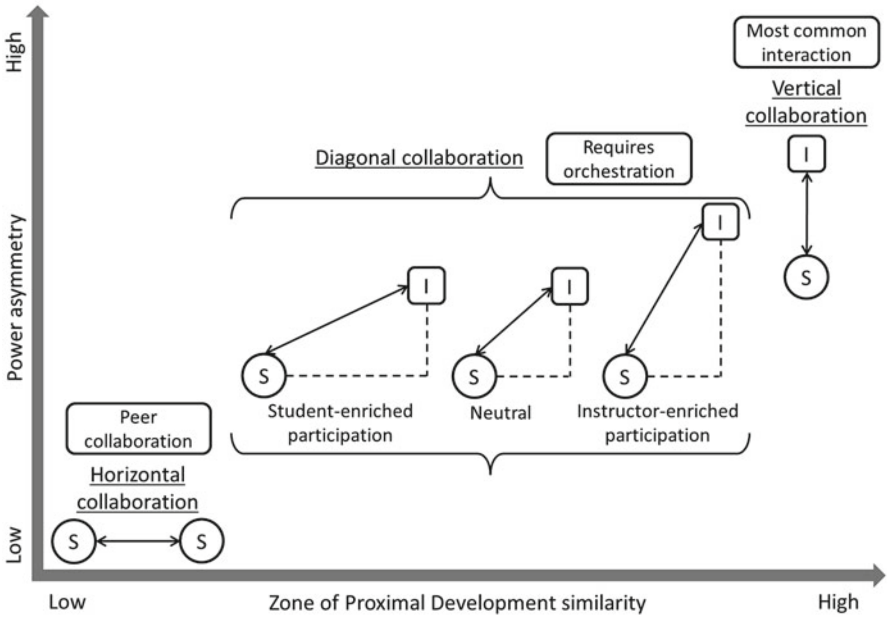

Fig. 11.5 Types of collaborative interactions that can occur during the learning process. Legend: *I*—instructor (*squares*) and *S*—students (*circles*)

of the ease of relating it to the supportive role of visualisation tools. CKC can be understood as a succession of three steps, (1) externalisation, followed by (2) elicitation of task-relevant knowledge, which precedes (3) consensus building, which can be oriented by integration or conflict (Fig. 11.6).

Externalisation of task-relevant knowledge is an individual effort to organise and clarify one's mental models in preparation for the collaborative discussions performed during the following steps (see the need for focusing on few important ideas in Fig. 11.6). Personal understandings, views and feelings appear as idiosyncrasies, and they shape the synthesised product of externalisation, which can be an individual N-Cmap that precisely captures the meanings of one's thoughts during the convergent thinking effort imposed by externalisation. Individual preparedness is critical to achieving good results during a collaborative process, and mapping the externalisation step is helpful to allow students to organise and retrieve their own knowledge.

Elicitation explores the students' ZPD similarities, allowing them to use their partners as a resource through discursive dynamics involving questions (elicitation) and answers (externalisation). The individual N-Cmaps prepared by each student can be used as starting point for discussion, while their idiosyncrasies are considered by the group (see the diversity of understanding from the same topic in Fig. 11.6). After reading an N-C map, the participants can easily identify doubts, mistakes or aspects (concepts) to be further developed. Good questions of

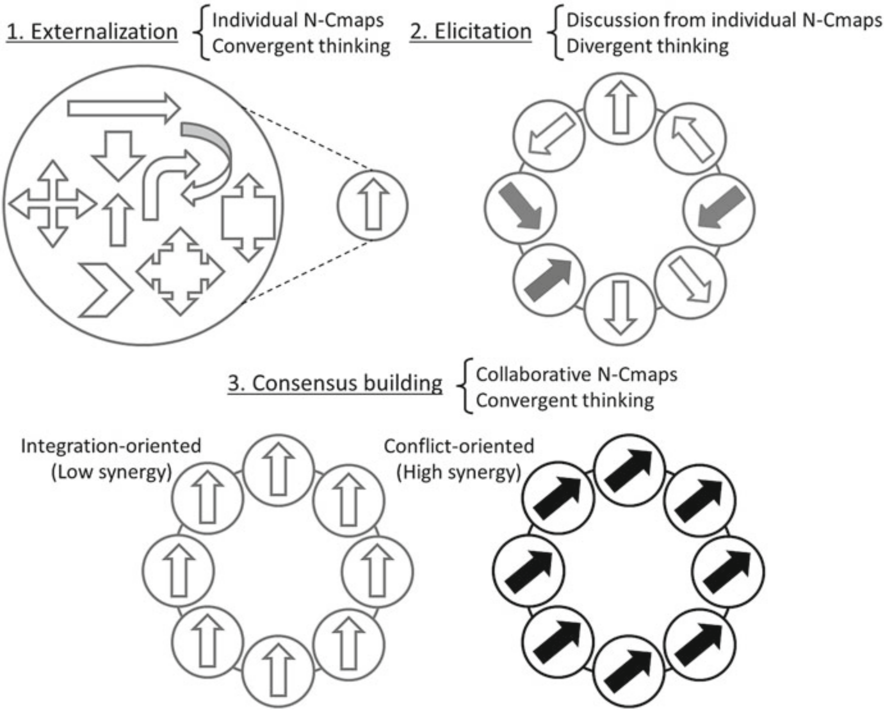

Fig. 11.6 Schematic representation of the collaborative knowledge construction steps

well-prepared map-makers are frequently the result of an elicitation session supported by individual N-Cmaps, and the students usually stay focused on the task for the entirety of the time allotted by the instructor. Students may have insightful, sparkling ideas that are identified through louder groups and "A-HA" moments. These special moments have been the empirical evidence we used to identify the student-enriched diagonal collaboration in our classrooms. The instructor's role is restricted to scaffolding the collaboration, and students are fully committed to creating meaning from the educational task.

Consensus building is challenging because it follows an animated divergent thinking session (elicitation) and imposes convergent thinking on the group. The aim is to obtain a final product that expresses the richness of the discussions, merging the participants' contributions into a combined framework produced by the group. Collaborative N-Cmaps are recommended to foster consensus building, requiring the students to merge their ideas into a single propositional framework.

Under non-ideal conditions, consensus will be reached through the integration of various individual perspectives into a common interpretation. Frequently, it characterises a superficial conflict-avoiding collaborative approach, and the final product is comparable to a mosaic in which all fragments have an identifiable authorship and most are from the same participant (see the new grey up arrows representing the leader who directed the integration-oriented consensus building in Fig. 11.6). A low synergistic effect is observed with this approach, and there is a tendency on the part of the students to reach an “illusionary consensus” (Fischer et al., 2002). Conflict is the preferred pathway to reach synergy during collaboration. In this situation, it is difficult to identify individual authors in the final product (see the new black arrows representing the synergistic product obtained through conflict in Fig. 11.6). Teamwork skills are critical to achieving this conflict-oriented consensus, and all learning organisations appreciate conflicts of ideas among their members (Senge, 1994).

3 Making Interdisciplinary Links Visible Using N-Cmaps and Knowledge Models: A Case Study

3.1 Research Setting

The School of Arts, Sciences and Humanities (SASH) was founded in 2005 as the new campus of the University of São Paulo (USP) located in São Paulo, one of the largest metro areas in the world. The SASH admits 1,020 new students each year, and they can choose from among ten different 4-year undergraduate courses of study. Founded in 1934, the USP is a prominent research university that can be considered as a reference for the Latin American higher education system (Correia, do Valle, Dazzani, & Infante-Malachias, 2010).

Recent changes towards a knowledge society and economy have challenged USP to revise and transform some of its higher education paradigms, which had, until recently, been based on knowledge fragmentation and the traditional focus on specialisation. The innovative curriculum designed for the SASH includes a “Basic Cycle” to address the challenge of introducing a holistic perspective into the traditional specialised undergraduate curriculum (Table 11.1). During the first year, all SASH students have 8 h of introductory classes per week in their particular fields of specialisation as defined by their undergraduate course of study (grey boxes in Table 11.1), and the remaining 12 h are devoted to contemporary issues (*problematiques*). Half of this time is allotted to six “General Courses” devised to promote

Table 11.1 Typical schedule for a first year student at the School of Arts, Sciences and Humanities (SASH/USP)

Time	Mon	Tue	Wed	Thu	Fri
M: 8-9.45am A: 2-3.45pm E: 7-8.45pm					
Break	-	-	-	-	-
M: 10.15-12pm A: 4.15-6pm E: 9.10.45pm					

Legend: morning (M), afternoon (A) and evening (E)

Table 11.2 Brief description of the six "General Courses" that are part of the "Basic Cycle" offered to all first-year students

Courses	Main topics to be covered
First semester	
Natural sciences (Co1)	• Origin, organisation and evolution of the Universe, Earth and life • Mutual relationships among science, technology and society in twenty-first century • Environmental challenges, advances in molecular biology and the need for bioethics
Data treatment and information analysis (Co2)	• Introductory concepts of statistical methodology and scientific thinking • Multiple methods of social, cultural and scientific data collection and information • Multiple possibilities of reading, interpreting and analysing data.
Society, multiculturalism and rights (Co3)	• Study of modern and contemporary societies under the approaches of anthropology and sociology • Analysis of differentiated, unequal, multiracial and multi-ethnic complex societies that were formed in modernity
Second semester	
Psychology, education and contemporary issues (Co4)	• Role of psychology in the study of contemporary issues related to our lifestyle, involving how violence, sexuality, health, quality of life and other issues interfere in human relations present in social institutions
Society, environment and citizenship (Co5)	• Contemporary issues that permeate society and their relationships with the environment and citizenship
Brazilian art, culture and literature (Co6)	• Formation of the Brazilian culture from the study of aesthetic and artistic languages and their interrelationships

interdisciplinary studies of relevant current questions involving democracy, inequality, technology and science, environment, multiculturalism, culture, arts and citizenship (vertical lines in Table 11.1). One day is for a course planned according to problem-based learning principles (white boxes in Table 11.1), whereas a 2-h course called "Diverse Studies" is offered to complement the students' skills acquired in high school (black box in Table 11.1).

All classroom activities described in this chapter were performed during a "Diverse Studies" assignment on "Knowledge Management with Concept Mapping to Learn How to Learn" during the second semester of 2011. The interdisciplinary connections among the six "General Courses" offered to the students were used to introduce them to hierarchical reductionism as an approach to address complex problems. Table 11.2 shows a brief description of the main topics covered by the "General Courses" to allow the reader to get a sense of the potential relationships one may find among their contents. Peer collaboration was explored to implement the collaborative knowledge construction supported by the N-Cmaps.

Fifty-two first year students were invited to develop KMs to characterise these interdisciplinary links from their own perspectives. The general structure devised for these KMs used one broad-view N-C map to organise the detailed contents of each "General Course" in six focused-view N-Cmaps. The former is the Level-1 N-Cmap, and the latter are the Level-2 N-Cmaps of the KMs developed by the

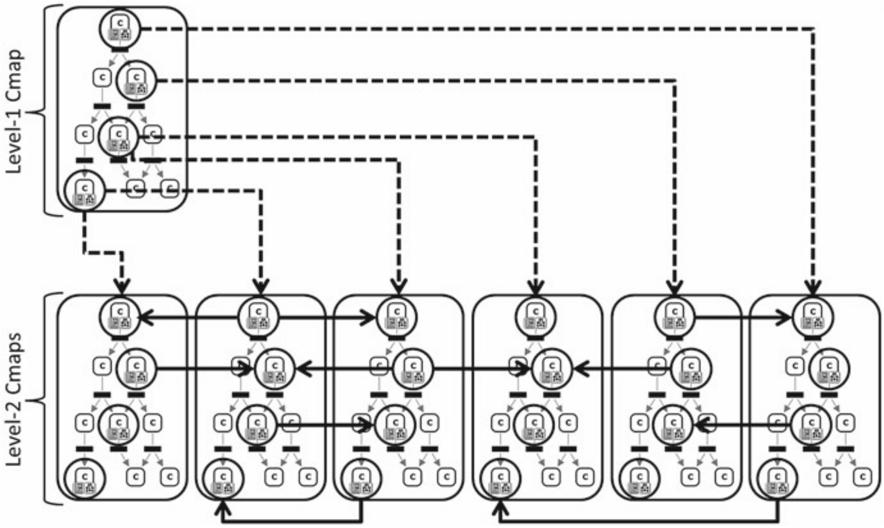

Fig. 11.7 General structure of the KM that represents interdisciplinary connections among the six "General Courses". Legend: horizontal links (*continuous lines*) and vertical links (*dotted lines*)

students (Fig. 11.7). Each N-Cmap could not have more than 25 concepts to keep it readable (no restrictions were imposed regarding the number of propositions and links). All hyperlinks among these N-Cmaps can be classified into vertical and horizontal, considering the N-Cmaps involved, defined as follows:

- Vertical hyperlinks involve N-Cmaps from different levels (Level-1 and Level-2), expressing the overarching structure of the "Basic Cycle",
- Horizontal hyperlinks involve N-Cmaps from the same level (Level-2), expressing interdisciplinary connections among the "General Courses".

"Basic Cycle" interdisciplinary relationships may become visible to the students through the horizontal links they make in their KMs. This is a straightforward strategy to determine course connections from their contents and to foster productive discussion about interdisciplinary curricula among students and faculty members.

3.2 Procedures

3.2.1 Data Collection

Table 11.3 describes the procedure to develop KMs through peer collaboration. They can be created in 7 weeks including 1–2 h of extra time of homework assigned to the students between two consecutive classes. We used CmapTools to make N-Cmaps and KMs with the students throughout the classes.

Table 11.3 Procedure for preparing knowledge models about the SASH "Basic Cycle"

Step	Task descriptions and goals
1. Preparation of individual N-Cmap (Level-1: broad scope)	• Make an individual N-Cmap to address the focus question: "*What is the Basic Cycle?*". Inclusive concepts (no more than 25) should be used to express a broad perspective of the Basic Cycle organisation • Goal: externalisation. Clarify one's idiosyncratic mental models about the Basic Cycle
2. Collaborative peer review of individual N-Cmaps (Level-1: broad scope)	• Make a collaborative N-Cmap from the individual ones made in step 1. Peer collaboration occurs in small groups (4–6 students) • Goal: elicitation and consensus building. Use partners as a resource through asking and answering questions (elicitation), and build a conflict-oriented consensus (synergistic collaborative effect)
3. Preparation of individual N-Cmap (Level-2: focus on first semester courses)	• Make individual N-Cmaps to address the focus question: "*What is course X?*", where X is Co1, Co2 or Co3. Each student is responsible for mapping only one course. Specific concepts (no more than 25) should be used to express the content related to the mapped course • Goal: externalisation. Clarify one's idiosyncratic mental models about the courses offered during the first semester
4. Collaborative peer review of individual N-Cmaps (Level-2: focus on first semester courses)	• Make a collaborative N-Cmap from the individual ones made in step 3. Peer collaboration occurs in small groups (4–6 students), according to the mapped course (Co1, Co2 or Co3) • Goal: elicitation and consensus building. Use partners as a resource through asking and answering questions (elicitation) and build a conflict-oriented consensus (synergistic collaborative effect)
5. Preparation of individual N-Cmap (Level-2: focus on second semester courses)	• Make individual N-Cmaps to address the focus question: "*What is course X?*", where X is Co4, Co5 or Co6. Each student is responsible for mapping only one course. Specific concepts (no more than 25) should be used to express the content related to the mapped course • Goal: externalisation. Clarify one's idiosyncratic mental models about the courses offered during the second semester
6. Collaborative peer review of individual N-Cmaps (Level-2: focus on second semester courses)	• Make a collaborative N-Cmap from the individual ones made in step 5. The peer collaboration occurs in small groups (4–6 students), according to the mapped course (Co4, Co5 or Co6) • Goal: elicitation and consensus building. Use partners as resource through asking and answering questions (elicitation) and build a conflict-oriented consensus (synergistic collaborative effect)
7. Collaborative KM elaboration	• Organise a KM from the collaborative N-Cmaps made in steps 2, 4 and 6. Include links among the Level-1 and Level-2 N-Cmaps, as well as other digital resources (e.g. audios, documents, images, URLs, videos) • Goal: hierarchical reductionism and consensus building. Organise a large amount of information about different topics and from many sources using hierarchical reductionism as an approach to managing complexity

Training for beginners is critical to avoid the naive use of N-Cmaps in the classroom. Kinchin (2001) highlighted the need to consider the “teaching ecology” to be sure that concept mapping will produce the expected results. The teaching ecology is seen as the total teaching environment and develops from the preparedness of instructors, the motivation of students, and the conditions in which teachers and students communicate effectively as partners within a learning community. Accordingly, a 4-class training period on concept mapping was provided before starting the development of knowledge models. Three methodological strategies (half-structured N-Cmaps, expanded collaborative learning and propositional clarity table) are used to boost the training session (Correia, Infante-Malachias, & Godoy, 2008).

3.2.2 Data Analysis

The KMs ($n=3$) elaborated by students are considered to be the most relevant research data to assess how students integrated the different “General Courses”. The following three approaches were considered to extract information from these KMs:

- A quantitative description of the KM’s main features, including mean and standard deviation of concepts, propositions and links.
- A quantitative description of the horizontal links to check how students connect the contents from the “General Courses”. We used a course correlation matrix to represent all the horizontal links that the students set up to assess students’ latent information from the perceived interdisciplinary connections.
- A qualitative description of the concepts and the way they were used to link the “General Courses”. We used a word cloud created by Wordle to get an at-a-glance view of the most used concepts (Viégas, Wattenberg, & Feinberg, 2009). One list containing all concepts that had links between the courses ($n=117$) was the primary data for world cloud generation. Finally, we tracked the propositions made by students using the more frequent concepts to check the meaning of propositions used to express the connections among the “General Courses”.

3.3 Results and Discussion

3.3.1 Quantitative Characterisation of KMs

The concept, proposition and link means and standard deviations allowed the verification of the main characteristics of the KMs. In Table 11.4, the data are organised by the N-Cmap level, which differentiates the broad (Level-1) and focused (Level-2) perspectives on the interdisciplinary connections among the “General Courses” (Fig. 11.6).

Table 11.4 Quantitative data (means and standard deviations for concepts, propositions and links) of KMs

	Level-1 N-Cmap	Level-2 N-Cmaps					
		Co1	Co2	Co3	Co4	Co5	Co6
Concepts	25 ± 5	17 ± 3	16 ± 1	18 ± 2	17 ± 2	16 ± 2	16 ± 1
Propositions	40 ± 6	22 ± 2	21 ± 2	22 ± 3	22 ± 7	22 ± 4	22 ± 5
Links	11 ± 7	21 ± 7	9 ± 5	15 ± 5	20 ± 8	14 ± 8	16 ± 2

Comparing the values presented in Table 11.4, the Level-1 N-C map has the highest average amount of concepts and propositions. However, the average of links in Level-1 N-Cmap is lower than Level-2 N-Cmaps for all courses, except for Co2. Because the KMs were developed using hierarchical reductionism, it is expected that the Level-1 N-Cmaps would be more generic and inclusive, thereby contributing to the use of a higher number of concepts and propositions and a lower number of links. In contrast, the fact that Level-2 N-Cmaps are more specific and less inclusive requires a judicious selection of concepts and propositions in addition to a higher number of links because of the high level of N-Cmap detail.

Comparison of the Level-2 N-Cmaps reveals that the number of concepts and propositions in each course (Co1–Co6) varied slightly. This pattern can be explained by the procedure used for the preparation of N-Cmaps (see Table 11.4), because the maximum number of concepts was capped at 25. Although the number of propositions was not limited, the restriction of the number of concepts, in this case, influenced the number of propositions. The high average values for the use of digital resources (links) in Level-2 N-Cmaps were the students' response to the stimulus we provided. Moreover, this type of material is suitable to provide further information about concepts, and this awareness of details is more present in Level-2 N-Cmaps. Therefore, we hypothesise that students preferred adding digital resources to detail concepts in Level-2 N-Cmaps, keeping the Level-1 N-C map with few links, which were mainly to the other N-Cmaps of the KM. The difference in the amount of links among Level-2 N-Cmaps is related to the content of each "General Course", and the following sections will delve further into this discussion.

3.3.2 Horizontal Links to Assess Interdisciplinary Connections

The horizontal links represent all connections involving the concepts of Level-2 N-Cmaps. Therefore, we can check how students connected the courses' contents using a correlation matrix for each KM to express the frequency of links between each pair of "General Courses". Table 11.5 shows the sum of the correlation matrixes for all three KMs, representing all links students made among the "General Courses".

The course with the lowest number of links was Co2 (Data Treatment and Information Analysis), revealing that it is different from the others. Its isolation can be explained not only by its specific features but also by the poor connection between the processes of collecting data and information (its core focus, see Table 11.2) and the issues discussed by the others "General Courses".

Table 11.5 Horizontal links involving the Level-2 N-Cmaps of the KMs

	Co1	Co2	Co3	Co4	Co5	Co6
Co1	–	–	–	–	–	–
Co2	9	–	–	–	–	–
Co3	21	4	–	–	–	–
Co4	3	1	8	–	–	–
Co5	7	3	3	22	–	–
Co6	2	1	4	19	11	–
Culture	Sci	Sci	Hum	Hum	Hum	Hum
Semester	First	First	First	Second	Second	Second

One of the highest numbers of links was observed between Co1 (Natural Sciences) and Co3 (Society, Multiculturalism and Rights). These links represent connections between the two academic cultures, as proposed by Snow (1998). While Co1 is related to the hard sciences, Co3 is linked to the humanities. These relationships are highly desirable, because seeking interdisciplinarity can be understood as a movement to intertwine these two cultures (sciences and humanities). Other high amounts of links involved Co4 (Psychology, Education and Contemporary Issues) with Co5 (Society, Environment and Citizenship) or Co6 (Brazilian Art, Culture and Literature). In both cases, the coupling occurs between courses with elements of the same culture (humanities). Despite the isolation of Co2, its correlation with the other discipline (Co1) of the same scientific culture fostered a greater number of links compared to the links with other courses in the "Basic Cycle".

The temporal factor is another key aspect that seems to interfere in the relationship among the courses. This factor can be exemplified by the following three relationships: Co1 (Natural Sciences) with Co3 (Society, Multiculturalism and Rights), Co4 (Psychology, Education and Contemporary Issues) with Co5 (Society, Environment and Citizenship) and Co4 with Co6 (Brazilian Art, Culture and Literature). In all of these cases, the courses occur simultaneously (first, second and second semester, respectively). When we observe the relationship between courses that occur in different semesters, the number of links is smaller than a course in the same semester, showing that the temporal cohesion of courses is an important factor for promoting disciplinary connections.

The analysis of the KM horizontal links reveals the following three aspects that may be considered when designing a curriculum to foster interdisciplinary connections:

- The level of specificity of each course.
- The alignment of the course's culture (scientific or humanistic).
- The simultaneous offering of courses, which can connect courses from the two cultures, as proposed by Snow.

3.3.3 A Closer Look at the Horizontal Links: Searching for more Meaning

The frequency of concepts with links among the "General Courses" was estimated using a word cloud obtained by Wordle (Fig. 11.8). The more frequent concepts are in large letters, while the less frequent concepts are in small letters.

Fig. 11.8 Word cloud obtained from all concepts used as link among the "General Courses" Co1–Co6 (wordle.net)

Table 11.6 Means and standard deviation of propositions using "society" as concept in the Level-2 N-Cmaps

Courses					
Co1	Co2	Co3	Co4	Co5	Co6
2.7 ± 0.6	0.0 ± 0.0	5 ± 2	2.3 ± 0.6	4 ± 2	1 ± 2

The concept that was most frequently used as a link between "General Courses" was "society" (more than 26 % of the total). This concept was relevant to the students' expression of how they understand the whole picture including all "General Courses" and the "Basic Cycle" attempt to manage a holistic view of *problematiques*. Based on the word cloud, it was possible to mine the data to identify how students used "society" in their KMs. Table 11.6 shows the average amount of propositions involving "society" for each course, taking into account the 3 KMs developed by the students.

Society, Multiculturalism and Rights (Co3) and Society, Environment and Citizenship (Co5) presented the highest means of propositions using society as concept in N-Cmaps Level-2. Both courses have "society" in their names, reinforcing its importance as one of the main topics they cover (see Table 11.2). Although these courses presented high numbers of propositions, the approach to discussions involving society is different, as we can see in the following examples of propositions:

- Society—is composed of → multiculturalism (Co3)
- Society—has a → political organisation (Co3)
- Society—needs → citizenship (Co5)
- Society—needs → sustainable development (Co5).

Intermediate values for propositions using "society" were found in Co1 (Natural Science) and Co4 (Psychology, Education and Contemporary Issues), revealing that it is a secondary topic (but not less important) that has to be covered in these "General Courses" (see Table 11.2). The following examples of propositions show the context for the discussion of "society" in these courses:

- Society—requires → ethics (Co1)
- Technology—helps the → society (Co1)

- Individuals—compose the → society (Co4)
- Contemporary society—induces to → individualism (Co4).

Brazilian Art, Culture and Literature course (Co6) presented a low value of propositions using “society”. The issues related to society are mentioned in a superficial way, making it a coadjutant concept to the topics that are covered during the course. This was a curious revelation for us, because we would have imagined that connections involving society, art, culture and literature would appear due to their relevance. However, there were a few good propositions involving society and Co6 by one group of students:

- Society—generates the → cultural industry (Co6)
- Society—shapes the → national identity (Co6).

The lack of propositions using “society” for Data Treatment and Information Analysis course (Co2) should to be highlighted. The specific and singular feature of Co2, previously mentioned, contributed to a lack of connection involving the course’s contents and “society”. As “society” seems to be the connection among the “General Courses”, this fact confirms the isolation of Co2. Rather than exclude it from the “Basic Cycle”, we believe there is a need to rethink the way that the content is organised. New instructional strategies can be pursued to make the social relevance of statistics more clear, as well as to connect the content with the other “General Courses” (especially the Natural Science course).

4 Final Considerations and Future Perspectives

A new pedagogic architecture is proposed by combining digital N-Cmaps and the hierarchical reductionism method. This strategy generates a student-enriched diagonal collaboration that allows their active participation to create a KM (hypertext). The epistemological and collaborative challenges to grasp complexity are overcome using this innovative approach. Our case study involved the creation of a KM to characterise the interdisciplinary connections among six undergraduate courses offered at the SASH/USP. Students’ outcomes about “Basic Cycle” interdisciplinarity confirmed they could organise and process information avoiding cognitive overload. The KM structure guided students through the collaborative knowledge construction process without giving any answer to them about how to address the posed question.

The theoretical framework underlying our instructional proposal is useful to expand the applications of N-Cmaps and the hierarchical reductionism method to explore hypertexts in other situations involving the need to understand complex issues through a collaborative effort. Our society presents this kind of challenge in many places beyond higher education classrooms and individuals aware of developing learning organisations can take advantage of exploring “*problematiques*” using a more-structured approach. We believe the ideas presented in this chapter can be easily adapted for other settings and knowledge areas to achieve similar results.

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Part III
Advances in Assessment Using Digital Knowledge Maps

Chapter 12
Assessment for Learning Using Digital Knowledge Maps

David L. Trumpower, Mehmet Filiz, and Gul Shahzad Sarwar

Abstract As the importance of formative assessment, assessment tools that evaluate the structure of one's knowledge, and computer-based assessment are becoming increasingly recognized, it is worthwhile to consider if and how digital knowledge maps can be utilized as assessment to support learning. In this chapter, we present evidence that digital knowledge maps do indeed meet the criteria deemed necessary for effective formative assessment—they validly assess higher-order knowledge, identify specific conceptual strengths and weaknesses of students, provide feedback that can be used to effectively improve learning, and can be user friendly for both students and teachers. We conclude the chapter with a discussion of several recently developed formative assessment systems meeting these criteria that rely extensively on the use of digital knowledge maps.

Keywords Structural assessment • Formative assessment • Computer-based instruction • Feedback

1 Introduction

Although knowledge maps, concept maps, and other structured visual representations of domain knowledge have been used as pedagogical tools for several decades, their application to assessment in general, and formative assessment in particular, has been less commonly utilized in the classroom. This may be due to teachers' unfamiliarity with how to use knowledge maps in this capacity and/or the amount of time and effort required for them to do so. However, digital technologies are providing ways to overcome such obstacles. In this chapter, we discuss how digital knowledge maps can be used as formative assessment to support student learning.

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We begin this chapter with a discussion of formative assessment, including consideration of criteria needed to ensure its effectiveness. We then examine evidence regarding whether or not knowledge maps, in general, and digital knowledge maps, in particular, meet these criteria. We conclude the chapter by describing several examples of digital knowledge map-based tools being developed to help make the formative assessment process easier and more effective.

2 Formative Assessment

2.1 Definition

Formative assessment has been defined as "the collaborative processes engaged in by educators and students for the purpose of understanding the students' learning and conceptual organization, identification of strengths, diagnosis of weaknesses, areas for improvement, and as a source of information that teachers can use in instructional planning and students can use in deepening their understandings and improving their achievement" (Cizek, 2010, pp. 6–7). Thus, the identifying purpose of formative assessment is to facilitate student learning. This is in contrast to *summative* assessments, such as large-scale standardized tests of achievement, final exams in a course, licensing exams, language proficiency tests, and even thesis defenses, all of which are intended to assess some end product of learning or training for the purpose of classifying the performance of the student relative to others or relative to a defined standard and subsequently to make decisions about whether or not the student obtains course credit, licensing, a degree, acceptance into a program, and so forth. Earl (2003) describes this distinction between the purposes of formative and summative assessment as assessment *for* learning versus assessment *of* learning, respectively.

It should be realized from the definition above that formative assessment is an ongoing process (for a good discussion of this point, see Good, 2011). Although the process begins with the use of an assessment instrument to obtain information about students' current knowledge, it does not end there. That information serves as the basis of feedback to both the student and teacher about where the student is in relation to educational objectives. The feedback, in turn, serves as a basis for developing and focusing further remedial learning activities. Following these ongoing learning opportunities, reassessment may occur, sometimes via self-assessment and peer assessment, and the process of feedback and ongoing learning continues. In addition, the types of assessment instruments to be used in a classroom can have an effect on students' initial learning strategies. For example, if students expect to be assessed using multiple choice tests, then they may attempt to memorize facts, whereas if they know that they are going to be assessed with structural assessments like knowledge maps, then they are more likely to try to understand concept relationships. Thus, the formative assessment process involves what occurs before, during,

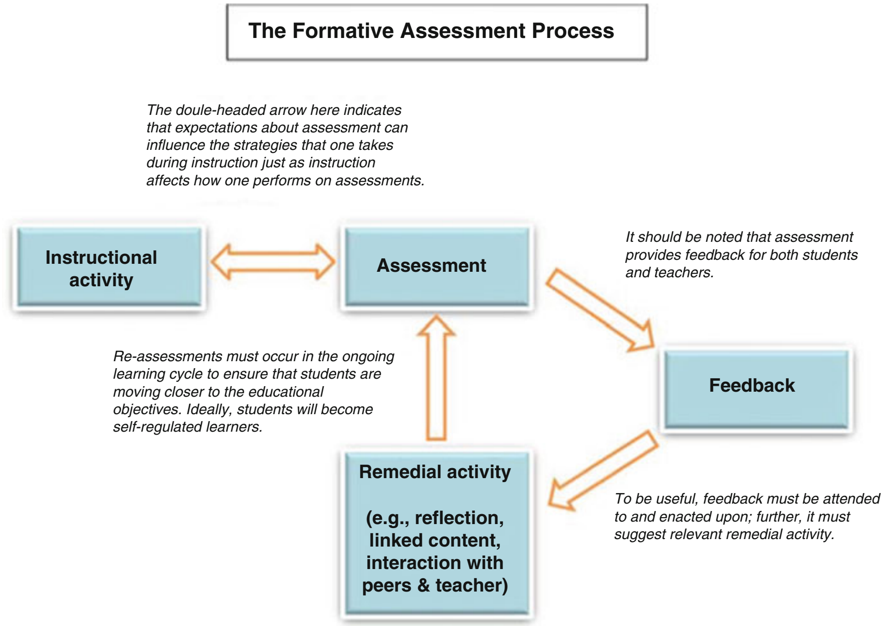

Fig. 12.1 This figure illustrates how assessment, feedback, and instructional/remedial activities can interact to improve learning

and after assessment to improve learning, and feedback can flow both forwards and backwards. The entire formative cycle is depicted in Fig. 12.1.

2.2 *General Effectiveness*

In their seminal review of formative pedagogical practices, Black and Wiliam (1998) concluded that formative assessment is one of the most powerful influences on student learning. Other reviews have summarized the effectiveness of formative feedback more specifically (Hattie & Timperley, 2007; Shute, 2008). More recently, Gikandi, Morrow, and Davis (2011) conducted a review of online formative assessment, concluding that it has the potential to engage both teachers and students in meaningful educational experiences, offers enhanced interactivity with feedback, and provides opportunity for self-regulated learning. Therefore, it is clear that formative assessment *can* be effective.

However, some have criticized the empirical evidence in favor of formative assessment on the grounds that it is a broad concept that can encompass many different pedagogical practices, among other issues (Bennett, 2011; Dunn & Mulvenon, 2009). Thus, whereas some instantiations of formative assessment may be effective, others may not. In response to this criticism, some researchers have been able to identify specific characteristics of effective formative assessment practices.

2.3 Criteria Required for Effectiveness

Gibbs and Simpson (2004) list the following ten "conditions under which assessment supports learning":

1. Sufficient assessed tasks are provided for students to capture sufficient study time.
2. These tasks are engaged with by students, orienting them to allocate appropriate amounts of time and effort to the most important aspects of the course.
3. Tackling the assessed task engages students in productive learning activity of an appropriate kind.
4. Sufficient feedback is provided, both often enough and in enough detail.
5. The feedback focuses on students' performance, on their learning, and on actions under the students' control, rather than on the students themselves and on their characteristics.
6. The feedback is timely in that it is received by students while it still matters to them and in time for them to pay attention to further learning or receive further assistance.
7. Feedback is appropriate to the purpose of the assignment and to its criteria for success.
8. Feedback is appropriate in relation to students' understanding of what they are supposed to be doing.
9. Feedback is received and attended to.
10. Feedback is acted upon by the student.

It can be noted that some of the conditions above are somewhat overlapping and interrelated. For instance, conditions 1 through 3 are all related to the assessment task, whereas conditions 4 through 8 are focused on characteristics of the feedback generated, including how and when it is provided, and conditions 9 and 10 both refer to what students do with the feedback. Others have compiled similar lists based on review of the formative assessment literature (see, e.g., Cizek, 2010; Nicol & Macfarlane-Dick, 2006).

Trumpower and Sarwar (2010) have consolidated the conditions necessary for effective formative assessment into four broader criteria, as shown in Table 12.1. Here, too, the criteria relate to characteristics of the assessment task and characteristics of the feedback. In order to be effective, the formative assessment process must first validly assess relevant knowledge. But what is meant by relevant knowledge? The National Research Council has recommended that assessment should evaluate how a student organizes acquired information, i.e., their conceptual knowledge (2001). This recommendation is based on the recognition that successful application of knowledge depends on an organized understanding of learned material. Consistent with this recommendation, Shepard (2009) argues that valid formative assessment must focus on higher-order, transferable, conceptual understanding as opposed to lower-order rote memorization. Thus, relevant knowledge means conceptual knowledge.

Table 12.1 Criteria for effective formative assessment

Criteria	Evidence
Assess higher-order knowledge	– Similarity between student and referent knowledge maps is associated with educational outcomes, including inferencing, problem solving, comprehension, etc. – Knowledge map scoring methods have been shown to be valid and reliable
Identifies specific strengths and weaknesses	– Absence of specific links in student knowledge maps is associated with specific types of errors on independent tasks
Provides useful feedback	– Students learn effectively from structure displayed by expert knowledge maps – Students learn effectively by reflecting on similarities and differences between experts' knowledge structure and their own knowledge structure – Students learn effectively by studying additional instructional content recommended by discrepancies between experts' knowledge structure and their own knowledge structure
Is user friendly	– Digital knowledge map-based formative assessment systems include automated assessment, evaluation, and feedback mechanisms – Students access and benefit from feedback in digital knowledge map-based formative assessment systems – Students and teachers report satisfaction with digital knowledge map-based formative assessment systems

Boston (2002) clearly points out that "assessments become formative when the information is used to adapt teaching and learning to meet student needs." This statement highlights the requirement that formative assessment must also be specific. That is, it must identify a student's particular strengths and weaknesses. If it does, then a teacher (or the students themselves) can potentially provide individualized remedial instruction in an effort to improve each student's learning.

But, even if the assessment is specific, there is no guarantee that the feedback that it generates will translate into effective remediation. Heritage, Kim, Vendlinski, and Herman (2009) have shown that teachers are more adept at identifying students' strengths and weaknesses than they are at deciding how to use such specific feedback in order to modify subsequent instruction. Thus, the formative assessment process must provide effective feedback for remediation.

Finally, the entire formative assessment process must be easy to use if it is to be implemented in the classroom. Indeed, the National Research Council (1999) has found that many teachers view formative assessment as an unnecessary addition to their already heavy workloads. We suspect that students may feel the same. Thus, formative assessment must be user friendly if it is to have a chance to succeed.

To summarize, we believe that the formative assessment process must assess higher-order knowledge, identify a student's specific strengths and weaknesses, provide feedback that can be used to effectively improve learning, and be user friendly. Next, we discuss the potential shown by structural assessment techniques, such as knowledge maps, to meet each of these four criteria.

3 Use of Knowledge Maps in Assessments for Learning

3.1 Can Knowledge Maps Meet Criteria for Effective Formative Assessment?

Traditionally, knowledge maps have been used for a variety of purposes in education. Students create knowledge maps as an instructional activity and teachers use their own or expert knowledge maps to help design and deliver instruction. Less common, although gaining in interest recently, is the use of knowledge maps for assessment. As there has been increasing recognition of the importance of both formative assessment and the development of structural knowledge as an important educational outcome, it seems logical to ask whether or not structural knowledge assessments, such as knowledge maps, can be used effectively to support learning.

In the review of online formative assessment techniques conducted by Gikandi et al. (2011), concept maps were notably absent. In this section we will, therefore, examine evidence concerning the potential for knowledge maps in general, and digital knowledge maps in particular, to meet the criteria required for effective formative assessment. In the subsequent section, we will examine in more detail several formative assessment systems based on the use of digital knowledge maps that are currently under development.

3.1.1 Assess Higher-Order Knowledge

Assessment based on knowledge maps and other structural representations of knowledge typically involves comparison of a student map to a referent expert map, although referent-free evaluation is possible. Although different scoring methods have been developed, with different strengths and weaknesses (e.g., Chang, Sung, Chang, & Lin, 2005; Clariana, Koul, & Salehi, 2006; Keppens & Hay, 2008; McClure, Sonak, & Suen, 1999; Passmore, 2004; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005), the general procedure has been shown to provide a valid measure of higher-order knowledge. For example, Goldsmith and Johnson (1990) found that the degree of similarity between student and referent knowledge maps is significantly positively correlated with traditional measures of domain knowledge, such as course grades and exam performance. More importantly, they showed that the quality of one's knowledge structure is more strongly correlated with performance on more conceptual, higher-order knowledge measures such as essays than on lower-order knowledge measures such as multiple choice exams (although it might be pointed out that Ifenthaler (2011) has found that student-generated knowledge maps and texts do not represent the exact same aspects of knowledge—whereas essays capture the breadth of one's knowledge, knowledge maps represent one's understanding of the structural relations among concepts).

Others have, likewise, found that measures of knowledge structure are related to higher-order skills such as problem solving, drawing inferences, and transfer

(Anderson et al., 2004; Baxter, Elder, & Glaser, 1996; Trumpower & Goldsmith, 2004). As well, Hay (2007) has demonstrated that qualitative analysis of students' knowledge maps constructed before and after an instructional episode can distinguish meaningful, deep-level learning from less meaningful, surface-level rote learning. Thus, as noted by Nesbit and Adesope (2006), knowledge mapping requires higher-order knowledge such as detection/understanding of important semantic relations, identification of central ideas, as well as lower-level details. Collectively, these studies therefore provide strong evidence that knowledge maps do indeed meet the first criteria for effective formative assessment.

3.1.2 Identify Strengths and Weaknesses

Not only must a formative assessment tool be able to assess higher-order knowledge, it must also do so with a level of detail such that it identifies a student's specific areas of strength and weakness. Telling Johnny only that his level of understanding is below some standard does not go far in helping him improve his understanding. However, telling him that his understanding of the relationship between concepts A and B does not include consideration of concept C, but that his understanding of the relationships between concepts X, Y, and Z shows considerable insight provides much more guidance. The more specific the feedback, the more likely it can help guide remedial activities toward improvement. Typical schemes for evaluating the quality of knowledge maps generate overall scores, such as the degree of similarity between a student and referent map. While overall scores are useful for summative assessment, they are less useful for formative purposes. For formative assessment, more specific information is required.

Recently, Trumpower, Sharara, and Goldsmith (2010) have demonstrated the specificity of information that can be provided by knowledge map assessments. In their study, undergraduates with no prior training in computer programming learned about a simple computer programming language. Later, they were assessed on their structural knowledge of the language, as well as their application of the language to a series of problem-solving tasks. The problem-solving tasks were comprised of two different types of problems. Task analysis indicated that performance on one type of problem required knowledge of the relationships between the programming concepts of *If-then*, *Go-to*, and *Step*. Performance on the other type of problem, however, required knowledge of the relationships between the concepts of *Pointer*, *Position*, *Increment*, and *Assign*. It was found that students whose knowledge structures contained links between *If-then*, *Go-to*, and *Step* performed better on the former type of problems than students whose knowledge structures did not contain these links. Likewise, students whose knowledge structures contained links between *Pointer*, *Position*, *Increment*, and *Assign* performed better on the latter type of problems than did students whose knowledge structures did not contain these links. Therefore, it seems that evaluation of specific links in students' knowledge maps can be used to identify specific conceptual strengths and weaknesses.

However, simply identifying specific areas of conceptual understanding and lack thereof is not enough. An effective formative assessment process must also be able to clearly communicate information about those strengths and weaknesses and do so in a way that suggests and promotes action toward improved learning.

3.1.3 Provide Useful Feedback

Ifenthaler (2011) refers to feedback about one's mental models, externally represented by knowledge maps, as model-based feedback and notes that such feedback can be presented in various ways. First, simply providing a referent knowledge map that depicts well-structured knowledge to students, similar to providing exemplar essays or correct answers to an exam as feedback, may facilitate further development of their understanding. Second, providing students with both their knowledge map and a referent map for comparison may prove useful. And third, providing additional content, suggested by discrepancies between students and referent knowledge maps as being potentially fruitful areas to study, could be useful.

Indeed, a growing body of research demonstrates that students do benefit from being presented with an expert knowledge structure, either alone or in comparison to their own knowledge structure. Trumpower and Goldsmith (2004) used a digital knowledge map (with unlabeled propositional links) created by domain experts as a graphical organizer to present instructional content to a group of students. Students clicked on concepts in the map to access associated content. Later, this group outperformed control groups who were presented the same content organized differently on outcomes that included both conceptual and procedural knowledge measures. Similarly, Shaw (2010) found that students who studied information in a digital environment performed better on a related test and reported greater satisfaction with the learning activity, if the information was presented in an expert knowledge map format as opposed to a more standard browser-based format. Both of these studies indicate that students are capable of making meaningful inferences from the structure in expert knowledge maps.

Students have also reported that they understand and appreciate feedback comprised of their own knowledge maps superimposed over a referent map to highlight differences (Berlanga, van Rosmalen, Boshuizen, & Sloep, 2012). Further, directing students to reflect on such discrepancies has proven effective. Ifenthaler (2012), for example, found that students who were shown a referent knowledge map and constructed their own map on a problem-solving process, and were then prompted to reflect on differences, displayed greater development of structural knowledge than a control group that was not prompted to do so. Sarwar and Trumpower (2011) also found that requiring students to reflect on differences between their own knowledge map and a referent map facilitates learning. However, they further observed that students who generated conceptual reflections (i.e., reflections in which students were able to link their prior knowledge of concrete, real-world examples with new knowledge of conceptual relationships as identified in the referent knowledge map) showed greater conceptual knowledge development than those who generated procedural and, especially, declarative reflections.

Others have found that providing feedback comprised of both student and referent knowledge maps, along with supplementary instructional content related to any discrepancies between the two, is effective. In addition to requiring students to reflect on the knowledge maps, Sarwar (2011) asked students in other conditions to study personalized remedial content. The content was comprised of text, problems, and videos designed to explicate the conceptual relationships that the student did not fully understand as identified by comparing their knowledge map to a referent. Although simply comparing and reflecting on the knowledge maps had the most powerful effect, studying the supplemental content also led to significant improvements in students' conceptual knowledge. Wu, Hwang, Milrad, Ke, and Huang (2011) also obtained success by similarly providing students with individualized remedial material based on discrepancies between their knowledge map and a referent map.

As mentioned previously, teachers appear to be better at identifying strengths and weaknesses in their students than subsequently knowing how to use that information to modify instruction most effectively (Heritage et al., 2009). Fortunately however, the studies just described are generating evidence that feedback from knowledge mapping assessments can be useful in suggesting where to effectively focus ongoing learning activities. Such suggestions might be enacted upon by teachers, but, as shown by the research, can also be enacted upon by students through self-guided reflection or automatically built into the digital knowledge maps as linked remedial content.

3.1.4 Are User Friendly

Teachers find formative feedback to be an onerous task (NRC, 1999). Hand scoring knowledge maps can be quite time consuming, as can be providing effective feedback on any assessment task. Fortunately, digital knowledge maps can now be evaluated automatically (e.g., Clariana et al., 2006; Ifenthaler, Masduki, & Seel, 2011; Wu et al., 2011) and may also be utilized in computer-based systems that automatically generate feedback and associated remedial content (e.g., Filiz, Trumpower, & Atas, 2012; Wu et al., 2011), as demonstrated by the studies discussed in the next section.

User friendliness, however, must apply to both teachers and students for a formative assessment tool to be optimally effective. After all, feedback cannot be effective unless students use it. In this regard, there is evidence that digital concept maps are easily used by students to support learning. For instance, Shaw (2010) and Mackinnon (2006) both revealed that students prefer computer-based knowledge mapping tasks to alternative formats for presenting and interacting with instructional materials. As will be further corroborated by the following section, it appears that digital knowledge maps are often perceived to be user friendly.

3.2 Digital Knowledge Maps as Formative Assessment

In this section, we describe several current computer-mediated formative assessment processes based on digital knowledge maps in greater detail. We believe that each meets the criteria necessary for effective assessment for learning.

Hagemans, van der Meij, and de Jong (2012) used digital knowledge maps as a mechanism to provide feedback to students as they learned kinematics in a simulation-based inquiry learning environment. Within this environment, students learned by performing a series of assignments related to various kinematics concepts. Students accessed the assignments that they wanted to work on through a (referent) digital knowledge map. By selecting a concept in the map, students were provided with a list of assignments related to that concept from which to choose. As students completed the assignments, the oval-shaped concept nodes in the knowledge map became filled with green and/or red shading to indicate the percentage of related assignments that had been completed successfully (as indicated by the percentage of the oval shaded green) and unsuccessfully (as indicated by the percentage of the oval shaded red). The shading of the knowledge map was continually updated during the learning process. Thus, if a particular concept node was completely green, then the student would know that she had completed all of the assignments related to that concept successfully. As compared to two control conditions in which students were presented with either a knowledge map that was not color coded or just a list of the concepts (not color coded either), students who received feedback through the color-coded knowledge map performed better on a posttest of their conceptual, procedural, and structural knowledge. As well, they restudied more initially incorrect assignments. In a follow-up study, Hagemans et al. (2012) determined that the color-coded knowledge maps were effective, in part, because they make the relations between concepts explicit, but also because they suggest an optimal route in which to study the concepts for each individual student. Hageman et al.'s example illustrates the self-regulatory power of digital knowledge map-based formative assessment.

In the formative process of Hageman et al., a referent knowledge map is used, but student knowledge maps are not. In contrast, Berlanga et al. (2012) demonstrate how student knowledge maps can be generated and compared to a referent map as formative feedback. In the formative process that they have conceived, knowledge maps are created automatically from text that students have written using the Leximancer software (Smith & Humphreys, 2006). Leximancer reads text from electronic sources (e.g., Word documents, webpages, PDF files, etc.) and, based on the co-occurrence and proximity of words in the text, identifies concepts and relationships which it displays in the form of a knowledge map (see http://www.textinsight.net/content/leximancer for more information about Leximancer). In Berlanga et al.'s formative process, the resulting student knowledge map is then superimposed over a referent knowledge map, created in the same way from an expert's or group of experts' text(s), with any discrepancies in concepts and/or links highlighted. Users of this formative process judged the knowledge maps derived automatically from their written text to be accurate representations of their knowledge and reported that they could easily identify similarities and differences between their individual knowledge map and a referent knowledge map.

In contrast with the previous examples, students create their own knowledge maps in the following three formative assessment processes that we will describe. Schacter, Herl, Chung, Dennis, and O'Neil (1999) asked eighth grade students to generate knowledge maps, given a set of environmental science concepts. The students were also asked to search through information provided to them in a simulated World Wide Web environment in order to link relevant content to the concepts in their knowledge maps. They were also free to modify the structure of their knowledge maps (i.e., adding or deleting concepts and propositional links) as they deemed appropriate. Feedback concerning the quality of their knowledge structure was made available upon request throughout a 50-min session. This feedback was provided in the form of a list of concepts that needed "little," "some," or "a lot" of improvement. How much improvement was deemed necessary for any given concept was based on the percentage of propositional links to that concept in the student's map that matched links found in the referent map. It was found that students, on average, accessed feedback five times during their session. In a subsequent study using the same learning environment and task, but with teams of students rather than individuals, it was found that frequency of use of feedback was significantly positively correlated with a conceptual knowledge outcome measure (Hsieh & O'Neil, 2002). These studies demonstrate that feedback which highlights discrepancies between students and referent digital knowledge maps is relatively easily accessed by students (as indicated by the frequency of use in Schacter et al., 1999) and that the feedback is effective, [as indicated by the positive relationship between frequency of accessing feedback and learning gains in Hsieh and O'Neil (2002)].

Wu et al. (2011) have developed one of the more comprehensive digital knowledge map-based formative assessment systems to be evaluated to date. In their system, teachers provide students with a list of key concepts for a given subject. Students are then asked to organize the concepts in a knowledge map using the CmapTools software (Novak & Cañas, 2006). After submitting their completed maps, the system automatically compares them to a referent knowledge map and provides the student with feedback. This feedback is comprised of a chart indicating correct, incorrect, and omitted concepts and propositional links. For example, suppose that a referent knowledge map has a propositional link between Concept A and Concept B, but the student map does not. One row in the feedback chart would then look like this:

Concept A ? ?? <> There is a missing connection related to Concept A and another concept

In addition, supplementary instructional material associated with each incorrect and omitted propositional link can be accessed from the chart. After browsing the supplementary material, students can make changes to their knowledge maps and receive further feedback. If any of the changes are not successful, students are provided with additional supplementary material to help explain the misunderstood relation. Each revision of the student's knowledge map also receives a score that indicates its overall similarity to the referent map. Higher scores indicate greater completeness and accuracy. This feature allows students to monitor their progress as they interact with the system. Implementation of the system within a group of clinical nursing students revealed that it is generally easy to use and effective. As compared to a control group who also created and modified knowledge maps using the CmapTools software, but received only paper-based feedback from the teacher, students receiving the automated feedback from the system over the course of a 4-week study performed better on a posttest of their learning achievement, made more revisions to their knowledge maps, accessed more supplementary materials, and had a more favorable attitude toward the learning activity.

In our own lab, we have been independently developing a system much like the one by Wu et al. (Filiz et al., 2012; Sarwar & Trumpower, 2011; Trumpower & Sarwar, 2010), with several notable differences. Our proposed system also involves four stages: structural assessment, evaluation, feedback, and ongoing instruction. In the initial stage, students' structural knowledge is assessed by having them complete a digital knowledge map task. The set of concepts to be used in construction of the knowledge map is chosen by the teacher from a predefined list of concept sets. Each set corresponds to a particular topic or unit from a variety of academic subject areas. By predefining sets of concepts, we are able to create a repository of referent knowledge maps and related instructional content corresponding to each set. These referent maps and instructional content are created by teams of subject matter experts.

In our system, knowledge maps are created using the Pathfinder technique available in the Knowledge Network Organizing Tools (KNOT) software (Schvaneveldt, 1990). The Pathfinder technique requires users to rate the degree of relatedness between all pairs of a set of concepts. These ratings are then converted, using a scaling algorithm, into knowledge maps with unlabeled links. The Pathfinder scaling algorithm essentially examines the pattern of ratings across all pairs of concepts and generates links between pairs that received relatively higher ratings of relatedness than other pairs (see http://interlinkinc.net/Pathfinder.html for more information about Pathfinder).

In the second stage, the student's knowledge map is evaluated by comparison to the corresponding referent knowledge map. More specifically, each propositional link that is present in both the student and referent maps (referred to as *germane propositions*) and that is present in the referent map but not in the student map (referred to as *missing propositions*) is recorded by the system. The results of this evaluation are used to create feedback and ongoing instruction presented in the next two stages.

In the third stage, students are shown their knowledge map augmented by any additional missing propositions, highlighted by dotted lines (see Fig. 12.2). Thus, in our system, feedback is provided spatially, as opposed to the tabular format provided in the Wu et al. system. Also, students do not receive any numerical scores as feedback, although teachers do have the option of receiving quantitative scores of the similarity between student and referent maps if they wish to use the tool for a summative assessment. We made this conscious decision based on research that

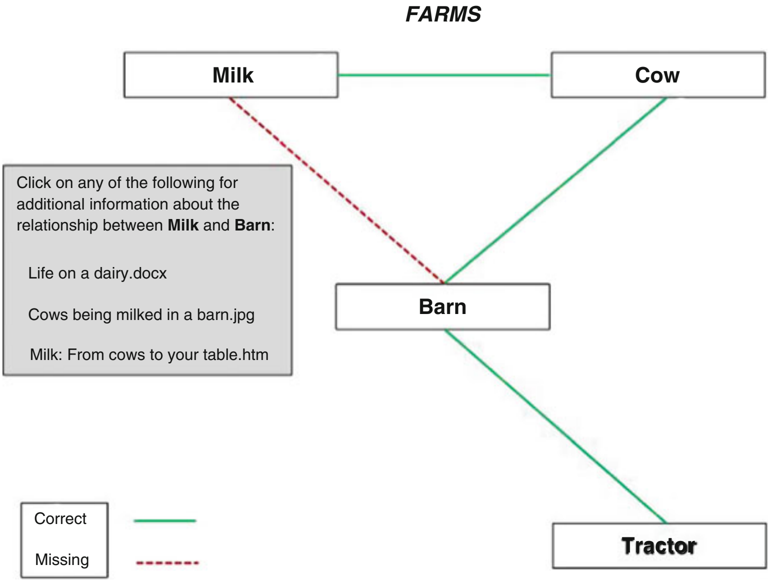

Fig. 12.2 This figure shows feedback provided to students on the topic of farms, as well as instructions on how to access additional content regarding discrepant links, in the system developed by the authors of this chapter

suggests students may not fully attend to formative feedback if it is accompanied by a score—students who receive high scores may feel that their knowledge is sufficient, whereas students who receive low scores may become dejected, with a result that neither considers the more beneficial aspects of the formative feedback (see Black & Wiliam, 1998; Nicol & Macfarlane-Dick, 2006).

Upon receiving the feedback, students are told that missing links indicate concept relationships that they may not have fully understood or considered. They are then asked to consider ways in which the concepts linked by dotted lines might be related and to give examples if possible. Students are prompted to write their responses in the space provided. The main purpose of this reflective phase is to make sure that students fully engage with the feedback. As noted earlier, prior research shows that reflection is a powerful learning activity. Teachers will also have access to the students' reflections and will be able to provide comments if they so choose. As indicated by Sarwar and Trumpower (2011), it may be helpful for teachers to prompt students whose initial reflections are more declarative or procedural to try to think of more conceptual, real-world examples of how the concepts are related.

In the fourth stage, the missing propositions become *active*. Students are instructed to click on the dotted lines for additional instruction intended to help them understand some ways in which linked concepts are related. This additional instruction may be comprised of text, problems, examples, and/or multimedia content such as instructional videos or games. The system contains a variety of such instructional content to illustrate the concept relationships indicated by each proposition in the referent knowledge maps. Although initial content has already been created by teams of subject matter experts, teachers who use the system will be able to add their own supplemental content if desired. After studying the additional content, students are free to create revised knowledge maps and receive further feedback and instruction.

As can be seen, the only input required by teachers when using the system is to choose which set of concepts they want to use. Thus, although we are in the early phase of building and user testing the system, it would appear to be very user friendly for teachers. Also, because it is based on the research and principles of effective formative assessment discussed in this chapter, we believe that it, like other digital knowledge map-based formative assessment systems that conform to these principles, can successfully improve student's conceptual understanding.

4 Conclusion

Educators are becoming more and more aware of the importance of assessment as a source of valuable information that both teachers and students may use to facilitate learning. But, despite this awareness of the value in formative assessment, teachers often feel limited in their ability to successfully implement it in their practice due to time constraints. Creating good assessment tasks that measure meaningful learning can take a considerable amount of time, and providing detailed feedback to each student after they have completed an assessment task may take even more time. And even if students and teachers have detailed feedback from a valid assessment task, they are often unsure about how to use it to proceed further toward achievement of learning objectives. Fortunately, the evidence reviewed in this chapter has shown that knowledge maps provide valid measures of higher-order knowledge, can identify specific areas of conceptual understanding and lack thereof in individuals, and generate feedback that is understood by, and useful to, students. And, digital technology allows knowledge map-based assessments to be easily implemented, with feedback generated nearly instantaneously and automatically. Further, the digital format allows feedback to be interactive and engaging, with remedial content and activities directly embedded within the feedback.

The computer-mediated formative assessment processes discussed in Sect. 12.3.2 all make use of one or more of these features of digital knowledge maps in order to meet the criteria of effective assessment for learning. For example, most of the processes discussed begin with an assessment task in which students create knowledge maps *directly* (Hsieh & O'Neil, 2002; Schacter et al., 1999; Wu et al., 2011) or *indirectly* via writing samples that are transformed into knowledge maps using Leximancer (Berlanga et al., 2012) or via ratings of concept relatedness that are converted into knowledge maps using Pathfinder (Filiz et al., 2012; Sarwar & Trumpower, 2011; Trumpower & Sarwar, 2010). These processes, thus, require students to use higher-order knowledge by thinking about concepts in a relational manner.

In all of these cases, the resulting student knowledge maps are compared to a referent knowledge map to generate feedback. Whereas some of the processes provide feedback in the form of *knowledge maps*, with the student's map superimposed over the referent to highlight any discrepancies (Berlanga et al., 2012; Filiz et al., 2012; Sarwar & Trumpower, 2011; Trumpower & Sarwar, 2010), others provide feedback as *lists* of concepts and relations in need of further study (Hsieh & O'Neil, 2002; Schacter et al., 1999; Wu et al., 2011). The one other formative assessment process reviewed (Hagemans et al., 2012) did not use a knowledge map-based assessment at all, but nonetheless used a referent knowledge map as the basis in which feedback was embedded about specific concepts in need of further study (as determined by performance on assignments comprised of problem-based multiple choice questions). Thus, all of the formative assessment processes reviewed provided individualized feedback about specific areas of strength and weakness. The processes that explicitly show a referent knowledge map may hold the additional advantage of providing a visual scaffold that students can use as they attempt to make inferences about concept relations that they may not have previously considered or may not have fully understood. Indeed, it has been demonstrated that reflecting on differences between one's own knowledge map and a referent map (Sarwar & Trumpower, 2011), or simply viewing the structure in a referent knowledge map (Trumpower & Goldsmith, 2004), are useful for learning.

Finally, some of the formative assessment processes provide supplemental materials and activities associated with any conceptual relationships identified as needing further study for each student (Filiz et al., 2012; Sarwar & Trumpower, 2011; Trumpower & Sarwar, 2010; Wu et al., 2011). These processes, thus, automatically indicate the next steps to be taken toward achievement of educational objectives.

Because the formative assessment processes discussed above are all multifaceted and use digital knowledge maps in a variety of ways, future research will be needed to determine which features are most effective and if results generalize across different subject areas and populations. Nonetheless, the findings to date are promising. Digital knowledge maps hold the potential for effective, engaging, and highly automated assessment for learning, thereby negating concerns about lack of time and/or ability to successfully implement assessment that supports student learning.

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Chapter 13
Sequentially Analyzing and Modeling Causal Mapping Processes that Support Causal Understanding and Systems Thinking

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Abstract A growing body of research shows that deeper understanding of complex systems can be achieved when students construct causal maps to articulate, explore, and refine their understanding. However, to what extent are students' maps an actual measure of their causal understanding versus the efficacy of different processes used by students to construct causal maps? To address this question, a set of methods was developed and implemented in this study to mine data from the causal mapping tool, jMAP; sequentially analyze the mined data; and construct transitional state diagrams to visualize, model, and compare students' causal mapping behaviors to identify differences in action sequences performed by students that created maps of high versus low accuracy. The causal maps of 17 graduate students enrolled in an online course on collaborative learning at Florida State University (USA) were sequentially analyzed and used to illustrate how the proposed methods can be implemented to capture, analyze, model, and identify causal mapping and reasoning processes that produce deeper causal understanding. Identifying and validating the most effective processes will enable software developers to create causal mapping software that can standardize the map construction process, control for individual differences in mapping skills, enable students to produce causal maps that accurately reflect their causal understanding (and/or help students to produce more accurate causal maps), and thus enable instructors to use such mapping tools to conduct automated large-scale assessments of students' causal understanding and systems thinking skills.

Keywords Sequential analysis • Causal understanding • Learner analytics

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1 Introduction

Causal maps, a network of nodes and links that define the causal relationships between nodes, have been used in science education as a tool for teaching and assessing learners' systemic understanding of complex problems and phenomena (Kali & Linn, 2007; Ruiz-Primo & Shavelson, 1996). Given that causal maps in theory represent learner's cognitive structures, their complex reasoning, and conceptual development (Jonassen & Ionas, 2008), causal maps can be and have been used to elicit, articulate, refine, assess, and improve analysis, identification, and understanding of the causes and causal mechanism underlying complex problems. The greatest improvements in students' understanding have been observed when students construct (either individually or collaboratively) their own maps as opposed to simply presenting students the instructor or expert maps (Nesbit & Adesope, 2006). Maps can be used to support collaborative learning when students compare their maps to identify, trigger, and focus group discussions around key differences in viewpoints and understanding (Jeong, 2009, 2010a).

To find new ways to help students construct better causal maps and improve learning, a growing number of studies have formulated various metrics to measure the accuracy and structural attributes of students' maps (parsimony, temporal flow, total links, connectedness). The goal is to identify the metrics and attributes that are correlated with map accuracy and therefore can be emphasized and presented to students as general guidelines to help them create more accurate maps (Ifenthaler, Masdsuki, & Seel, 2011; Jeong, 2009; Plate, 2010; Scavarda, Bouzdine-Chameeva, Goldstein, Hays, & Hill, 2006). For example, studies have been conducted to determine how different constraints imposed on the map construction process affect student's maps and learning—constraints like imposing hierarchical order by allowing students to move and reposition nodes (Ruiz-Primo, Shavelson, & Schulz, 1997; Wilson, 1994), providing terms for nodes (Barenholz & Tamir, 1992), providing labels for links (McClure & Bell, 1990), and allowing more than one link between nodes (Fisher, 1990). Among these studies, software tools have been developed to automate and reliably measure both the accuracy and the structural attributes of maps. Software programs like HIMATT (Ifenthaler, 2010) and jMAP (Jeong, 2010b) have been developed to address issues of rater reliability and validity by using the software to measure and test the correlation between different structural attributes and accuracy (Ifenthaler et al., 2011), as well as to measure how maps change over time and how these changes over time contribute to convergence in shared understanding between learners (Jeong, 2010).

However, measuring the *structural attributes* of students' causal maps does not appear to provide useful guidelines that will help students construct more accurate causal maps because (a) the many if not most of the structural attributes examined in prior research (Ifenthaler et al., 2011) have not been found to correlate with map accuracy and (b) structural attributes may be largely dependent on the nature or complexity of the problem, domain, or system. Furthermore, Jeong and Lee (2012) found that the effects of an attribute can differ depending on how or when they are implemented during the instructional task and what particular outcome one is trying to achieve. For example, the study's findings suggest that (a) causal understanding during initial map construction can be adversely affected if students are instructed to temporally sequence nodes to flow from left to right and position the outcome node farther away from the left edge of the map relative to other nodes in the map, (b) causal understanding achieved during the later process of map construction following class discussions on proposed causal links can be increased by instructing students to minimize the number of causal links and create a map with left-to-right temporal flow, (c) temporal flow can make the greatest impact among the three attributes on the ratio of root causes correctly/incorrectly identified, and (d) minimizing number of links can make the greatest impact on understanding how root causes directly/indirectly impact outcomes.

At the same time, students' maps will vary widely in accuracy when maps are compared to expert maps regardless of what interventions are used to help improve the quality and accuracy of students' maps (Ruiz-Primo & Shavelson, 1996; Scavarda et al., 2006). Based on their review of the empirical research, Ruiz-Primo and Shavelson (1996) concluded that maps should not be used in the classroom for large-scale assessments until students' facility, prior knowledge, skills, and processes used to create the maps, as well as training techniques, are thoroughly examined. As a result, the alternative approach to finding ways to help students construct more accurate causal map is to first identify the *processes* or action sequences that produce more accurate maps. These types of action sequences can include actions at both the local level (e.g., move node→link node to affected node→redirect existing link to point to mediating node→specific causal link strength) and global level (work forward versus backward from outcome node using inductive versus deductive approach, work breadth versus depth first to identify multiple contingent causes versus causal chains). However, no prior research has been found at this time that has empirically identified, tested, and validated specific action sequences that lead to increased accuracy despite the variety of guidelines and logic rules that have been developed to support causal mapping, root cause analysis, and systems thinking (Bryson, Ackerman, Eden, & Finn, 2004; Clarkson & Hodgkinson, 2005; Decision Systems & Inc., 2012; Jonassen & Ionas, 2008; Scavarda et al., 2006). The purpose of this study was to develop and apply a set of methods that can address the following questions:

1. What patterns exist in the action sequences performed by students that produce causal maps of high versus low in accuracy?
2. Which sequences of actions help students create more accurate causal maps?

2 Methodology

2.1 Procedure

To identify the action sequences that produce more accurate causal maps, seventeen graduate students in an online course on collaborative learning at Florida State University, USA were presented with an activity to articulate and formulate their

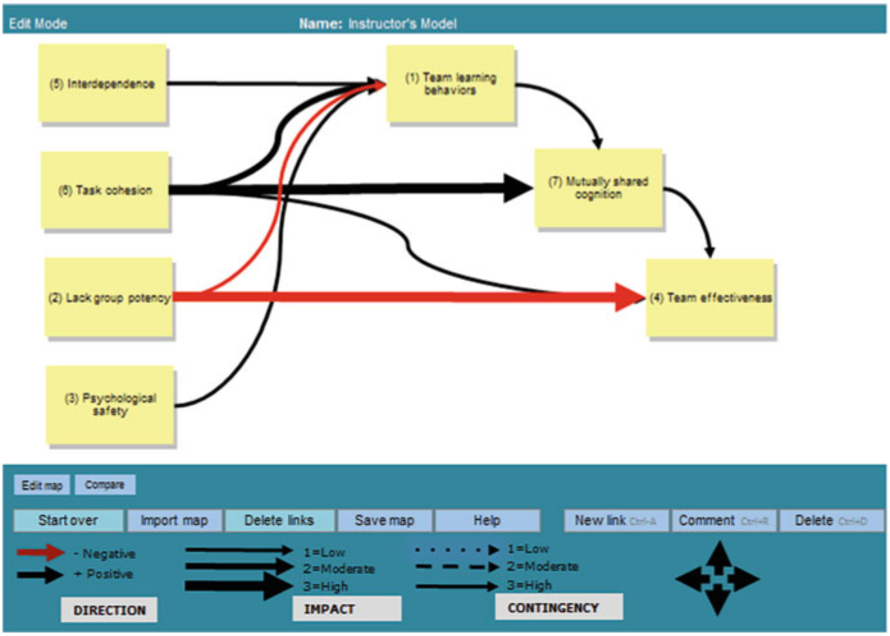

Fig. 13.1 Instructor's map used as criterion for assessing the accuracy of students' maps

personal theory as to how certain variables affect team effectiveness in collaborative learning projects. Students were instructed to use jMAP (Jeong, 2010) to individually create a causal map containing seven predefined variables believed to influence team effectiveness in collaborative learning groups (Fig. 13.1). Each student's goal was to construct a map to convey his/her personal theory as to how the seven variables might be causally interrelated and how they either directly or indirectly affect team effectiveness. The maps they produced were included and presented later in a graded written paper worth 20 % of the course grade. To help students produce theories that were not overly complex, easier to interpret, and hence more parsimonious, the total number of outward pointing arrows stemming from any one node in the maps was limited to a maximum of two. When a given node possessed two outward pointing arrows (and was believed to simultaneously affect two other variables), students were instructed to distinguish which of the two affected variables was most impacted by setting one arrow at "high" impact level and the other arrow at "moderate" impact level. Students were presented a video and practice activity to learn how to move and reposition nodes, insert links between nodes and affected nodes, change the density of the link to convey relative level of impact (high, moderate, low), and change direction of the causal relationship (positive = black, inverse = red). Students were required to log into a designated video conferencing room in Elluminate™ to video record the entire map construction session (limited to 45 min maximum). At the same time, the jMAP software logged each action students performed on their map from start to finish.

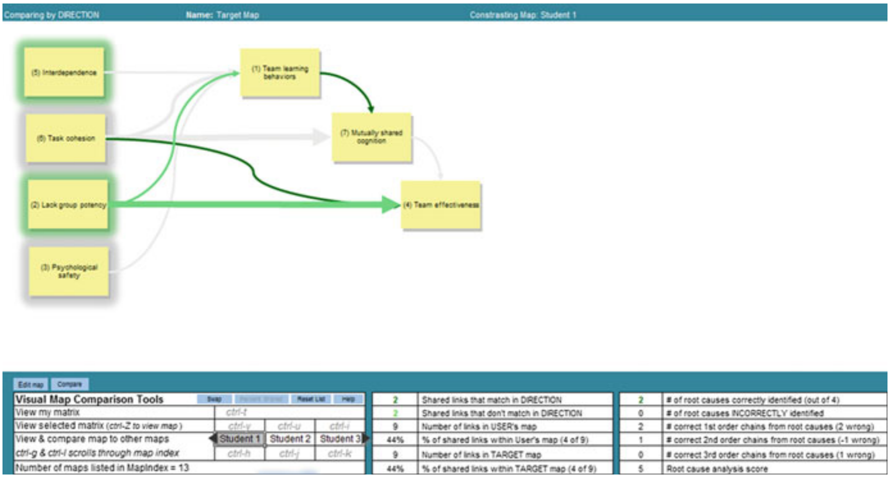

Fig. 13.2 jMAP's visual and quantitative assessment of student1's map

	Shared links that match in DIRECTION	% of shared links within User's map	# of root causes correctly	# of correct 1st order root links	# of correct 2nd order root links	# of correct 3rd order root link	Total Score
[illegible]	4	57.1%	2	1	1	1	95.71
[illegible]	4	44.4%	2	2	1	0	94.44
[illegible]	7	57.1%	0	0	0	0	75.71
[illegible]	6	23.1%	0	0	0	0	62.31
[illegible]	3	25.0%	1	0	0	0	42.50
[illegible]	4	15.4%	0	0	0	0	41.54
[illegible]	2	25.0%	1	0	0	0	32.50
[illegible]	2	18.2%	0	0	0	0	21.82
[illegible]	1	25.0%	0	0	0	0	12.50
[illegible]	1	12.5%	1	0	0	0	21.25
[illegible]	1	16.7%	0	0	0	0	11.67
[illegible]	1	16.7%	0	0	0	0	11.67
[illegible]	1	14.3%	0	0	0	0	11.43

Fig. 13.3 jMAP's ranking of students based on scores across six criterion measures. *Note*: Names have been blurred to maintain anonymity. First order = link stemming directly out of root cause (node with no inward-pointing links). Second order = link from node one link removed from root cause. Third order = link from node two links removed from root cause

2.2 Data Analysis

A total of 14 causal maps were submitted by the students. The maps were imported into jMAP and assessed in relation to the instructor's map (Fig. 13.2). The instructor's map was based on an empirical study that used path analysis to determine the relationships between the variables (Bossche, Gijselaers, Mien, & Kirschner, 2006). Scores from six criterion measures were each multiplied by 10 and summed to determine each students' total score (Fig. 13.3). The maps produced by students that

Table 13.1 Codes assigned to each action students perform in jMAP software

Final codes	Code	Definition
LINK	ADDR	Added new link pointing to the right
	ADDL	Added new link pointing to the left
	ADDU	Added new link pointing up
	ADDD	Added new link pointing down
	LK2	Attached link to the affected node
RELINK	RLK1	Redirected the existing link to a new causal node
	RLK2	Redirected the existing link to a new affected node
	ULK1	Detached the beginning tail of the link
	ULK2	Detached the end of the link
ATTR	ATT-	Changed link to color red to convey a negative or inverse relationship
	ATT+	Changed link to the color black to convey a positive relationship
	ATT2L	Changed link to low level of impact
	ATT2M	Changed link to moderate level of impact
	ATT2H	Changed link to high level of impact
DEL	DEL	Deleted the link
MOVE	MS	Moved a node (which was the same node as the last moved node)
	MDn	Moved node to the north of the previously moved node
	MDne	Moved node to the NE of the previously moved node
	MDe	Moved node to the East of the previously moved node
	MDse	Moved node to the SE of the previously moved node
	MDse	Moved node to the South of the previously moved node
	MDsw	Moved node to the SW of the previously moved node
	MDw	Moved node to the West of the previously moved node
	MDnw	Moved node to the NW of the previously moved node
COMM	COM	Added comment to link to explain how node influences affected node
	CREV	Revised the existing comment on the given link

achieved the top five and bottom five scores were selected for analysis. The jMAP software captured 26 mechanical actions that students performed while constructing their maps (Table 13.1). These 26 actions were collapsed and reduced to six final codes to facilitate the process of identifying overall patterns in students' action sequences.

Next, the code sequences produced by low performers were compiled into a single column in an Excel spreadsheet. The numeral 1 was placed in the cell immediately to the right of the first action performed by a given student to mark the first of a sequence of actions performed by each individual student. The six final codes and the sequence data were entered into the Discussion Analysis Tool (DAT) software (Jeong, 2012) to (a) compute the transitional probabilities between action pairs (Fig. 13.4), (b) compute z-scores at $p < 0.01$ to identify behavior "patterns"—transitional probabilities found to be significantly higher than expected (bottom of Fig. 13.4), and (c) generate a transitional state diagram to reveal the behavioral patterns exhibited by low scorers (left diagram in Fig. 13.5). This procedure was repeated using code sequences produced by the high performers to produce the transitional state diagram to the right in Fig. 13.5.

Frequency matrix

	MOVE	LINK	ATTR	COMM	RELINK	DEL	Replies	No Replies	Givens	% replies	% givens
MOVE	**259**	**32**	**10**	**7**	8	**5**	321	0	321	.45	.44
LINK	**31**	**97**	**42**	**8**	5	13	196	0	196	.27	.27
ATTR	**17**	34	**32**	8	0	4	95	2	97	.13	.13
COMM	**3**	**7**	11	**44**	0	1	66	3	69	.09	.10
RELINK	3	**8**	1	1	0	0	13	0	13	.02	.02
DEL	**3**	**18**	1	1	0	**6**	29	0	29	.04	.04
	316	196	97	69	13	29	720	5	725		

Transitional probability matrix

	MOVE	LINK	ATTR	COMM	RELINK	DEL	Replies	No Replies	Givens	Reply Rate
MOVE	**.81**	**.10**	**.03**	**.02**	.02	**.02**	321	0	321	1.00
LINK	**.16**	**.49**	**.21**	**.04**	.03	.07	196	0	196	1.00
ATTR	**.18**	.36	**.34**	.08	.00	.04	95	2	97	.98
COMM	**.05**	**.11**	.17	**.67**	.00	.02	66	3	69	.96
RELINK	.23	**.62**	.08	.08	.00	.00	13	0	13	1.00
DEL	**.10**	**.62**	.03	.03	.00	**.21**	29	0	29	1.00
	316	196	97	69	13	29	720	5	725	.37

Z-Score matrix

	MOVE	LINK	ATTR	COMM	RELINK	DEL	
MOVE	**17.85**	**-9.33**	**-7.30**	**-6.05**	1.24	-3.02	321
LINK	**-9.28**	**8.21**	3.82	**-3.07**	0.92	2.17	196
ATTR	**-5.48**	**2.01**	**6.19**	-0.41	-1.42	0.10	95
COMM	**-6.76**	**-3.18**	0.80	**16.53**	-1.16	-1.09	66
RELINK	-1.53	2.81	-0.62	-0.23	-0.49	-0.75	13
DEL	-3.72	4.30	-1.61	-1.15	-0.75	4.66	29
	316	196	97	69	13	29	720

Fig. 13.4 Screenshot of the DAT software output presenting the frequency, transitional probability, and *z*-score matrices. *Note*: *Bold* values = transitions significantly higher than expected ($p < 0.01$). *Bold underlined* values = transitions significantly below expected value

The DAT software (Jeong, 2012) is a Microsoft™ Excel-based application that sequentially analyzes temporal events to identify sequential patterns between events using techniques developed by Bakeman and Gottman (1997). The software was

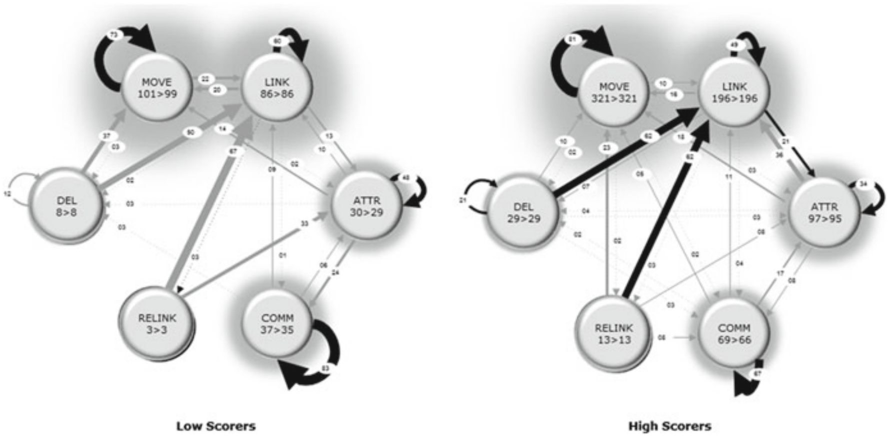

Fig. 13.5 Transitional state diagrams of action sequences performed by low versus high performers. *Notes*: *Black* and *gray arrows* identify probabilities that are and are not significantly greater than expected. *Arrows* are weighted in direct proportion to the observed transitional probability. The first and second numerical value displayed in each node identifies the number of times the given action was performed and the number of events that followed the given action. The size of the glow emanating from each node conveys the number of times the given action was performed

used to tally the number of times a particular action was performed, the total number of actions that immediately followed the given action, and the number of times each type of action immediately followed any one given action. For example, the frequency matrix in Fig. 13.4 shows that students in the high-scoring group moved or repositioned the nodes in their maps a total of 321 times (listed in MOVE row and GIVEN column). The number of actions that immediately followed each MOVE was 321 (listed under REPLIES column). When these students moved a node, this action was followed with more moving of nodes by a total of 259 times and adding of links by a total of 32 times. Next, the DAT software and spreadsheet converted the observed frequencies into transitional probabilities to convey how likely one event was to follow another given event (as displayed in the transitional probability matrix in Fig. 13.5). For example, the transitional probability between MOVE→MOVE was 81 % (or 259 divided by 321) given that 259 out of the 321 actions following a MOVE was another MOVE. In contrast, the transitional probability between MOVE→LINK was only 10 % (32 divided by 321).

To determine whether or not the transitional probability between any two actions was a behavioral pattern, *z*-scores were computed for each transitional probability and reported in the *z*-score matrix presented in Fig. 13.4. Each *z*-score determined whether a given transitional probability was significantly higher or lower than the expected transitional probability based on chance alone. A *z*-score that was significantly less than the critical *z*-score of −2.32 at alpha <0.01 identified a transitional probability that was significantly lower than the expected probability. These *z*-scores (and their associated frequencies and transitional probabilities presented in the frequency and transitional probability matrices) were underlined and highlighted in bold red-colored font. A *z*-score that was significantly greater than the critical *z*-score of 2.32 at alpha <0.01 identified a transitional probability that was significantly higher than the expected probability (values highlighted in bold green-colored font). The *z*-score statistic (Bakeman & Gottman, 1997) takes into account not only the observed total number of responses following each given behavior but also the marginal totals of each response observed across all behaviors. One important note is that paired actions with significant *z*-scores but with observed frequencies of less than 4 should not be identified as a behavioral pattern because the low cell frequencies are not sufficient in size to compute a reliable *z*-score.

Finally, DAT software was used to convert the observed transitional probabilities into two transitional state diagrams (a network of nodes used to represent each action linked or interconnected by lines/arrows that depict their sequential order) to provide a graphical and Gestalt view of the behavioral patterns produced collectively by the high- versus the low-scoring students (Fig. 13.5). The density or thicknesses of the arrows are directly proportional to the observed transitional probabilities between given nodes/behaviors so that high probabilities are identified with large thick arrows and low probabilities are identified with thin arrows. Arrows were either presented in solid black, to convey a transitional probability with a significant *z*-score, or in light gray, to present a transitional probability with a nonsignificant *z*-score. The relative size of the glow emanating from each node in the state diagrams conveys the relative frequencies in which each particular action was observed. For example, the left state diagram in Fig. 13.5 shows that students in the low-scoring group moved nodes a total of 101 times but commented on the links only 37 times. As a result, the size of the glow emanating from the MOVE node is 2.7 times larger (101 divided by 37) than the glow emanating from the COMM node. Finally, the first and second numerical value displayed in each node identifies the number of times the given action was performed and the number of events that followed the given action. These features of the transitional diagrams enable one to visually compare the state diagrams of the low- versus high-scoring students when placed side by side and, by doing so, identify the similarities and differences in behavior patterns produced by each group. The patterns that distinguish the high- from the low-scoring students help to identify processes that produce and/or explain how and when students produce more accurate causal maps.

3 Discussion

3.1 Low Performers

The transitional state diagram for low performers (Fig. 13.5) reveals four behavioral patterns. The patterns reveal their tendency to construct each component of their causal maps in separate discrete stages. These students tended to start first by moving multiple nodes into their respective positions. Once multiple nodes were positioned, they inserted links between the nodes one after another. Once links were added, these students specified the attributes of each causal link. In addition, once links were inserted, these students tended to insert their comments into one link (one link after another) to explain the causal mechanism underlying the inserted link.

3.2 High Performers

The state diagram for high performers in Fig. 13.5 also revealed the same four behavioral patterns exhibited by low performers. However, high performers exhibited four additional patterns. These additional patterns were attributed in part to how the higher performers relinked and deleted links more often than low performers. These patterns may help to explain how students can produce more accurate maps. The high performers exhibited the tendency to (1) specify the attributes of a causal link that is inserted between two nodes, (2) add a new link immediately after they redirect an existing link, (3) add a new link immediately after they deleted a link, and (4) delete another link immediately after deleting a link. These patterns serve as possible indicators that show that high-scoring students produced more accurate maps because they engaged more frequently in the process of iteratively revising their causal maps (DEL→AddLink; Relink→AddLink; DeleteLink→Delete AnotherLink). The observed patterns might also serve to demonstrate that high-scoring students applied rules of logic or reasoning like those embedded in the REASON software (Decision Systems & Inc., 2012). For example, a logical reasoning process can lead a student to realize that both A and B do not exert direct effects on C (when realizing that C can occur without A), but instead, A directly effects B, which in turn directly effects C. This line of reasoning involves the process of inserting links between A and C, and B and C, then deleting the link between A and C followed by adding the link from A to B or redirecting the existing A→C link that points to C so that it now points instead to node B.

The unique behavioral patterns observed among the high performers suggest that redirecting and deleting links are a critical part of the mapping process. To determine what prior actions tend to trigger Relink and Delete actions, the historical state diagram (Fig. 13.6) shows that (a) the event that was most likely to precede the Relink action was the Move action (62 % of all preceding events) and Link action (100 %) among the high and low performers, respectively, and (b) the event most likely to precede the Delete action was the Link action (45 % of all preceding events) and Move action (37 %) among the high and low performers, respectively. In general, the historical diagrams like the ones presented in Fig. 13.6 can be used to identify the triggers and/or prior actions that are most likely to initiate specific action sequences that are of key interest.

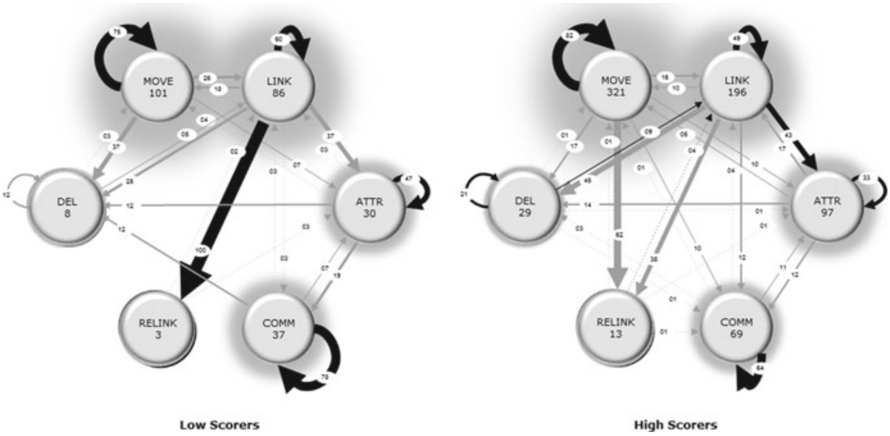

Fig. 13.6 Historical state diagrams of actions most likely to elicit given action performed by low versus high performers

4 Conclusion

The findings from this study illustrate how the presented methods can be used to identify specific action sequences that can be prescribed to help students produce more accurate causal maps and to achieve deeper causal understanding of complex systems. One way to improve on the methodology presented above is to include a pretest that measures students' prior understanding of the causal relationships to tease out the effects of prior understanding from the effects of individual differences in processes used by students on students' causal understanding. Because the number of causal maps examined in this study was too small in number to produce any conclusive findings, larger samples are needed to determine if the reported findings can be replicated. In order to identify and examine the logic rules and reasoning processes/strategies used by high-scoring students, the coding scheme will need to be refined in a way that can verify, for example, when a Relink is or is not redirected to a mediating node (where A→C and B→C is changed to A→B→C).

Furthermore, a more detailed breakdown and analysis of the mined data will be necessary to determine to what extent students use backward/deductive versus forward/inductive approach and/or depth versus breadth-first approach (work in progress), and ultimately to determine which approach is most effective. For example, the segment of data presented in Fig. 13.7 shows that the student linked node 7 to node 4. Immediately following this action, the student linked node 1 to node 7 to perform a backward or deductive reasoning process to produce the 1→7→4 causal chain. Immediately after linking 1→7, the student linked 7 to 5 to produce the 1→7→5 causal chain—an action sequence that illustrates a forward/inductive reasoning process. Both of these two behaviors serve to illustrate a depth-first approach to

Fig. 13.7 A segment of the mined data from jMAP used to measure deductive versus inductive reasoning processes

	A	B	C	D	E
1	5/17/2012 5:14:21 PM	Link#	ACTION	Given Node	Affected Node
245	5/17/2012 5:26:08 PM	17	LK2	N7	N4
308	5/17/2012 5:28:50 PM	24	LK2	N1	N7
336	5/17/2012 5:29:51 PM	41	LK2	N7	N5
351	5/17/2012 5:30:26 PM	47	LK2	N7	N4
432	5/17/2012 5:33:13 PM	49	LK2	N7	N4
469	5/17/2012 5:34:54 PM	54	LK2	N1	N7

identifying the causal chains. The data in Fig. 13.7 also shows that the student linked 7→5 and then linked 7→4 to produce two parallel causal chains that stem from node 7. These behaviors are indications that the student also used a breadth-first reasoning process.

Once the described method and tools have been refined and validated over time, further research and developments in the instructional application of knowledge mapping can be conducted by (a) integrating the target action sequences directly into causal mapping software interface to conduct controlled experimental tests to determine if the target processes increases map accuracy regardless of students' prior knowledge/understanding, (b) examining to what extent the target processes are effective across different topics that are and are not temporal in nature, and (c) revisiting and retesting criterion measures identified in prior research for assessing the accuracy or quality of knowledge maps while controlling for the specific processes students use while constructing their causal maps.

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Chapter 14
Gainfully Guided Misconception

How Automatically Generated Knowledge Maps Can Help Companies Within and Across Their Projects

Pablo Pirnay-Dummer

Abstract Conversations in and about the work processes have a considerable effect on the efficiency and overall process cost for all companies. But most companies trust this key aspect to everyday conversation heuristics that essentially only search for plausibility where the conversations then end. Automatically generated knowledge maps can help to guide existing misconceptions back to the conversation within and between different kinds of expertise, thus allowing more effective planning and monitoring. This chapter contains an introduction and discussion of a knowledge mapping method that only uses documents, which already exist within companies. The described approach will be useful for project managers, heads of organizational units, to improve team communication and ultimately performance (not sure if this is true but it needs a summative/conclusion/benefit statement).

Keywords Automated knowledge mapping • Association nets • Conversation efficiency • Work process • Talk at work • Knowledge management • Computer-supported collaborative work

1 Introduction

In companies that rely on human collaboration to make their profit a mutual understanding of the goals, work processes and the ways of communication are mandatory (Boxall & Purcell, 2011; Engelmann, Dehler, Bodemer, & Buder, 2009; Wenger, 2004). Probably no one would disagree with such a statement at the beginning of the twenty-first century. People need to know what they are doing and why in order to be productive and efficient (North, 2005; Simon, 2007a). To establish

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such an understanding, meetings usually are held that may or may not be followed by some kind of documentation.

This chapter does not investigate opinion or other disturbances in communication. Those aspects of human communication (Axley, 1996) are not ignored but set aside to shed light on the conceptual support of work-oriented communication within companies. Of course, the conversation needs to be at least sufficiently aligned to allow a working communication in regard to argumentation style, same thing as argumentation style, rhetorics, and personality.

2 Towards Understanding

Communicative actions towards understanding are carried out for only as long as there is a feeling of a lack of understanding. If everyone is satisfied—or at least the leader within a hierarchy—the conversation ends or is taken to another topic (O'Neill & Allen, 2012; Scott, Shanock, & Rogelberg, 2012). There is no further need for struggle. It's a natural and very trivial end of maybe the most common process between people: sending and receiving information by language until there is a sufficient amount of symbolic equilibrium between the participants, i.e., talking. But the bits that are sent are not necessarily the bits that are received.

They are rather reconstructed using the available current understanding of and by the receiver. He or she uses the content as part of the outside world behavior to immediately construct one or more models in order to understand it (Seel, 1991). Who sends the information usually has little or no real insight into that symbolic and relational (conceptual) "world" of the receiver and vice versa. To some not locally determinable extent, those "world knowledges" differ, even if the terms are the same. The terms that refer to concepts of individual understanding may differ, relations of similarly used terms may differ (conceptually), and finally the relations may differ due to different concepts that are referred to by the terms. These mechanisms are inherent to human communication and understanding. They may be facilitated by knowledge-driven technology, and they are a key factor for all face-to-face and computer-supported collaborative work (CSCW) environments. Where CSCW technologies aim at the collaboration, the access, and the aggregation of work processes (Xue, Shen, Fan, Li, & Fan, 2012), they have an evident blind spot at fostering understanding itself—which is also not their task (Reinmann, 2002).

2.1 Arranging Thought Towards Workflow and Performance Within Meetings

Implementing a new workflow or changing it requires various departments and groups to direct their attention to different things (e.g., production, R&D, sales, accounting) in different locations and at different times. This is essentially *why* meetings take place: to coordinate the efforts towards a common goal and to narrow down the misconceptions that would lead to a lower or no outcome. Communication is necessary until there is sufficient mutual understanding about the goal. Plausibility on the other hand does not suffice. It can even obstruct the goal.

First of all, the communication is not the work process itself; it is what happens to allow the work process to run better or to run at all at some later time. Thus, meetings often feel like a waste of time to the participants because they are not directly productive towards the goal but only prepare the implementation (Scott et al., 2012). Misled plausibility may again disturb this necessary preparation: “Why sit and discuss if everything is already clear?” Or even more self-directed: “Why do I always sit here and listen to nonsense. I already know what everybody should do, and I’ve even already told them.”

In order to understand both why this rejection is so common and how it can be avoided, it is necessary to recognize some basic aspects of the mental workings of plausibility and misconception.

2.2 Plausibility and Misunderstanding

Obviously, there will always be variations within the mental reconstructions of things depending on the different experiences and expectations of individuals (Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991; Seel, 1991, 2003; Spector, 2008; Strasser, 2010). None of the differences may become visible if there is no conscious reason to search for them. This fact does not always matter much, for instance if the differences do not harm the work progress. But even if the divergences between the conceptual “worlds” would matter because they are important for the work process, nobody will notice the gaps automatically as long as local plausibility overrules the search for misconceptions. Local plausibility is a satisfaction that occurs when there is a feeling of mutual understanding in a certain situation. Local plausibility feels like understanding to the participants of a conversation, but it is not congruent with it. It may also be opposed to real understanding—when satisfaction with the communication and the termination of the conversation happens too early—thus even hindering a common understanding.

Misplaced misconceptions may occur, when there is in fact a lack of mutual conceptual understanding but is attributed to a feeling of “different opinion” by ones opponent. In those cases the illusion of a difference between opinions may be induced and stabilized by a lack of mutual understanding of the others’ thought.

There are three types of sources for local plausibility of another ones’ world behavior:

- *Symbolic convention*. The use of words and sentences feels as if they are sufficiently aligned with others’ language use. Whether this is true or not cannot always be derived from a conversation.
- *Transformations*. The other participants come to conclusions that are understood and seem to resemble a mutual understanding.

- *Transactions*. Actions in the real world can be observed as behavior that is sufficiently aligned with the predictions given a sufficiently mutual level of understanding if these actions are plausible.

In meetings, participants usually rely on the symbolic impressions and transformations when conclusions are made clear. Even for the latter, a high skill in communication is necessary to carefully follow someone else's conclusions. Transactions can only be seen while actually working together, literally meaning moving and manipulating objects at the same time. Obviously not all work can be organized like this, especially when the work processes are long, complex, or require different expertise. With different expertise required, the problem becomes more complex on all three layers: experts from different fields use different languages even if they work in the same domain (Pirnay-Dummer, 2006). This has both an influence on the terms and their conceptual use and on the way they relate, i.e., how the knowledge is structured. All three layers are dependent: symbolic congruency is needed for transformations. Mutually agreed-upon transformations are necessary for proper actions if the work process is not supposed to rely on chance alone, and the participants need to be aware of the process (Engelmann et al., 2009). The next section will examine the congruency on the symbolic level.

2.3 Terms, Words, and Concepts

Various experts encode problems and parts of them differently. They may use the same terms but use them differently. And even if they know that a coworker is from another expertise and the experience tells them that they may use terms differently, this does not mean they thus understand the other ones' use of terms. For instance, if a learning scientist and a computer scientist talk about and use the term "learning" during planning and design, they may (or may not) already know that their concepts differ: it's obviously a long way between human learning heuristics and machine learning algorithms. But the concept they have on the other ones' concept is also not likely to be aligned, e.g., the computer scientists' concept on the learning concept of the learning scientist. But with this imposed concept, the computer scientist will predict what the learning scientist will or will not do, for example, during a developing phase.

Even with only two separate kinds of expertise, at least four concepts of the same term will be used during discussion:

1. The concept how the expert A uses it in the field A (own field), specifically how the computer scientist uses the term learning.
2. The concept how the expert B uses it in the field B (own field), specifically how the learning scientist uses learning.
3. The concept A: how expert B expects expert A to use "his" concept A, specifically how the learning scientist thinks that the computer scientist will use learning.
4. The concept B: how expert A expects expert B to use "his" concept B, specifically how the computer scientist thinks that the learning scientist will use learning.

Again, the term would be the same (that is "learning"). So, why don't they just look up their definition in some commonly accessible dictionary? Because it's not the definitions alone that matter but the use of the concept within decision-making processes (Aebli, 1981; Seel, 1991; Vygotskij & Kozulin, 1997; Wittgenstein, 1994). And the use of concepts is already oversimplified at this point. Omitted is the fact that even within an expert, the concept will vary depending on his or her understanding of the goal and all possible circumstances that are considered critical—by the individual expert (see Bach, 1968, 1989; Chiercha, 1983; Link, 2002).

The goal itself may have been provided by an implicitly felt need or (as in most cases) by another person—probably one with a different expertise. Moreover, between experts of the same field who work in the same domain, differences are to be expected (Dominowski, 1998; Jonassen, 2006).

2.4 Relations and Similar Things

But not the concepts and terms and their use alone are important for expertise. The one main feature of knowledge is how its concepts relate to each other. This issue is addressed in many of the other chapters of this book. There are different types of relations depending on the domain, the experts' way of thinking, and the task or goal for which the knowledge is used. Among others, there are cause-and-effect relations, part-whole relations, conceptual relations, propositions, numerical relations (flows between stocks), dynamic relations, functional relations, probabilistic relations (e.g., in Bayes Nets), and sub-symbolic (in connectionist networks). In the fuzziness of real-world understanding, relational types can even be mixed or unspecified, and the type of relation may or may not play a part in the use of the knowledge (Pirnay-Dummer, 2006). For machine processing the under-specification and fuzziness of the human knowledge use may pose lots of challenges. And, as stated before, for practical human communication that is driven towards a goal, it is not even possible to map the world completely. Its reason is to provide heuristics that are sufficient enough to create adequate overlaps for the actions that follow the communication. Understanding and communication use heuristics, and thus heuristics help by efficiently increasing the overlaps, especially those of the relations. Hence, what followed for the concepts follows even more for their relations: they need to be fuzzy in order to be successfully used by different worlds or belief systems between people. Otherwise, the struggle for a complete match in understanding will go on indefinitely without any resulting action. The latter may still be a great endeavor in itself and go on productively even for thousands of years in a philosophical manner. But for the time constraints that exist for everyday companies' work processes, a different approach is needed. Any technology that is supposed to be useful within the goals of companies has to fulfill two requirements regarding relations:

1. The fuzziness within and between the individuals knowledge needs to be preserved and conveyed to the knowledge map. Only then can more than one individual work with the map properly and freely discover his or her own thought within it.

2. The technology of a map cannot be limited to just one type of relation (e.g., causal). Even if a relation or a subset of relations is considered to map knowledge more powerful than others. Fulfilling this requirement will result in formal shortcomings towards every specific type of relation, which cannot be completely mapped as a necessary result of the requirement itself. But the map will cover more and different types of knowledge representations this way.

Relations need to be open within the knowledge map to fulfill the above requirements. This does not mean that they are not to be discussed while the knowledge map is used—on the contrary. But they need to be left open in order to be described and discussed by the users later on rather than to be prescribed by the map itself.

2.5 Reasoning

This will only be dealt with briefly: reasoning takes place as thinking on some model structure, always carries a set of symbols (simple and complex), and at least one evaluation function—most of the time, there are several. Reasoning can make use of logic but logic does not prescribe reasoning, its only one possible tool to it—not even the most commonly used. Humans use heuristics for a huge number of reasons. The reasoning heuristics support successful conclusions in many but not all of the cases, and most heuristics systematically fail when confronted with a specific class of problems (Johnson-Laird & Byrne, 1991). Successful means, that when changes to the world are applied, the one who drew the conclusion in order to act to change the world would be sufficiently satisfied with the results of the changed world behavior or world states. Reasoning is in a way the vehicle that connects all that is prior to action to the prediction and the evaluation of the results of that action. Thus, reasoning acts on the mental and concept relational model that represents the part of the world that is relevant to the specific situation. This also shows the huge role that individual reasoning plays in learning (Seel, Ifenthaler, & Pirnay-Dummer, 2009). Reasoning can be conscious but does not have to be conscious. Whether it is conscious or not plays a role for learning and also for understanding. Within meetings, a fast and complex set of reasoning processes are induced. These processes need to be focused in order to lead to any specific goal. Otherwise they will end up in endless chains of associations. But they also need to be free enough to allow the construction of something new. Both demands need to be balanced. This is particularly important if meetings are not moderated, which is the case for most meetings in companies.

3 Opportunities to Fail

A powerful way to help people who circle around decision-making processes is to give them additional opportunities to fail at their early plausibility. Just telling them that they must be wrong, because essentially everybody is wrong, will not help most of the times (McGregor & Cutcher-Gershenfeld, 2006; Senge, 1990; Simon, 2007b). But still, the awareness of a misconception creates a practical reason to take the conversation further and then, if guided properly, to resolve it.

Based on mental model theory, there would be two applied steps to induce a new circle of reflection. The first one covers the awareness of a possible misconception; the second one then carefully reconstructs a model within the communication that is not perfect either but better than the prior understanding (Pirnay-Dummer, Ifenthaler, & Seel, 2012; Seel, 1991, 2003; Seel et al., 2009).

3.1 Aim for the Discovery of Hidden Misconceptions

Suppose there is a project meeting in an ongoing project with a usual amount of time pressure. Certainly everyone who ever worked in any kind of team will remember such a meeting. For the sake of simplicity (only for the argument), it is assumed that everybody at the meeting is conceptually standing more or less on the same starting point at the beginning of the meeting. Everybody knows what the meeting is about, is prepared, and knows the overall goals and resources. In everyday meetings, this is truly not always the case. But if so, this strengthens the argument for the discovery of hidden misconceptions even more. During the discussion of the meeting, there is a point where the meeting is either adjourned or closed. The example will start at the point where a meeting or a series of meetings is complete. This is the case, when everybody (or almost everybody) has the impression to know where the project is going and what he or she needs to do in the time after the meeting to support the project. Excluded are also cases of miscommunication, inappropriate behavior, and political struggle, i.e., all cases where the communication is dysfunctional due to personal or political agenda, personality incompatibilities, different communications styles, or cultural differences. Such cases of miscommunication may pose additional threats to projects and also need to be taken into account by means of organizational development (Argyris & Schön, 1996; Senge, 1990; Wenger & Snyder, 2000).

Figure 14.1 shows the dilemma of different goal representation. From the understanding of the meeting, participant A (e.g., an accountant) has a completely different idea and representation of what was just agreed on than participant B (e.g., a product designer). This implies that they believe to be on the same side, so the differences are not due to different opinion but due to real conceptual misunderstanding. Suppose they also signed a protocol that verbally states their agreement. So, the goals are not only individually agreed upon but they are also documented. At this point, participant A believes they agreed on G_A and B believes it to be G_B. And even the wording of the goals is exactly the same, e.g., about introducing a new product. After two weeks of dedicated work on all ends, a stage is usually reached that is unsatisfactory to most if not all of the participants. Some goal in between P_R is reached. A participant, say A, remembers the goal G_A and that he or she did everything to achieve that goal. All the others must have done

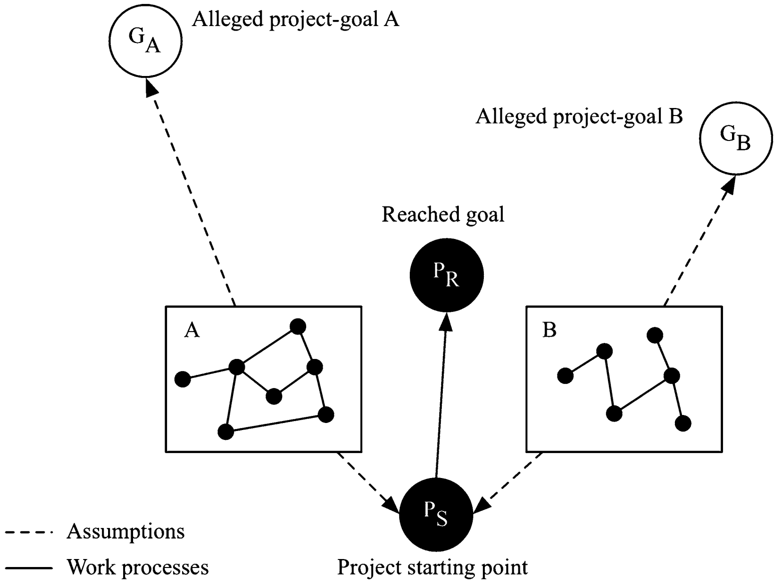

Fig. 14.1 Differences in goal representations lead to less overall project performance

something other than what they agreed on. Depending on the pressure and the stakes in the project, this may cause resentment. This resentment may then even be mistakenly derived back to bad communication—culture or lack of skill, especially when hierarchies are very strict. But some if not most of the misunderstandings may be found in conceptual misunderstanding. And due to the complexity of knowledge—especially expert-knowledge—simple definition will not solve the problem. Thus, the first goal is to allow the discovery of additional misunderstandings in order to narrow down the gaps that lead to mismatched kinds of actions in the work process.

3.2 Narrow Gaps (Outcome)

Interventions that direct the awareness of the participants back to resolving misunderstandings after reaching the point where plausibility would have normally been reached can help with the problem: overlaps in understanding of the concepts and relations will provide for a better match. But the process of narrowing down the gaps is only carried out until a sufficient level of plausibility is reached. At that point external strategies are needed to keep narrowing the gaps until the understanding of the goal set is sufficiently aligned—even within a perfectly established communication culture. In order to narrow the gaps further, tools are required that do not normally belong to the arsenal of everyday communication. Such tools need to provide external opportunities to discover additional misunderstandings. The use of such

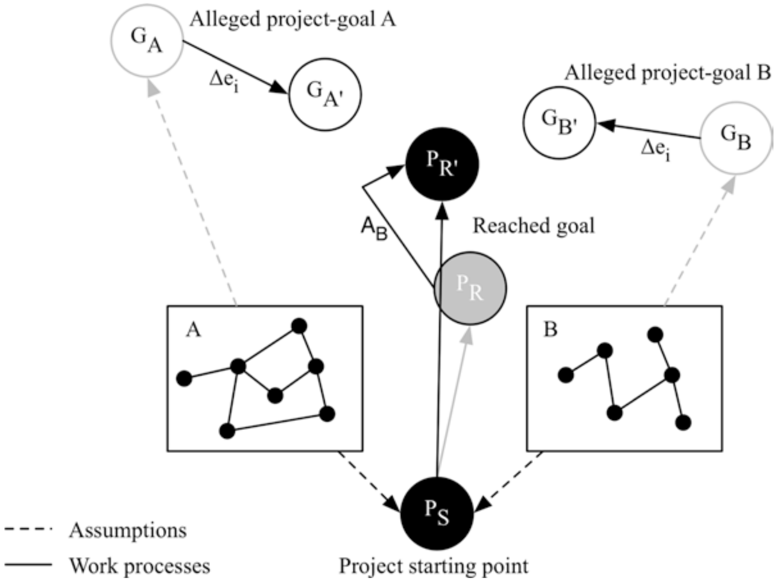

Fig. 14.2 Knowledge map adapted action benefit

tools takes different kinds of efforts that need to be justified alongside the cost and effect. Both theory and research allow the conclusion that a complete match between the different conceptual and relational "worlds"—the different episteme—is impossible. But by narrowing the gap, the action cost towards the goal will be reduced from its initial effort $A_{C.0}$ by the adapted action benefit (transfer) from the reduced level of misunderstanding. The new action costs $A_{C.1}$ are thus simply

$$A_{C.1} = A_{C.0} - A_B$$

The adapted action benefit A_B is the sum of all participants' closing in to a more common understanding of the goal, including the efforts that are necessary to conduct the additional communication with the tools because the reflection of the overall project—and sometimes even its visualization or documentation—is a subtask that every participant needs to perform anyway.

Thus the sum is a gain from the deviation between the plausible alleged goal after the conversation and the corrected alleged goal after the additional use of the tool (see also Fig. 14.2):

$$A_B = \sum_{i=1}^{n} \Delta e_i$$

The new alleged goals (G_A' and G_B') will still contain misconceptions and misunderstandings. But they are now more focused than before. Thus they improve the performance vector towards a common goal. A new goal is achieved after spending the labor on the project. The effect of unaligned goal representations is still active, but the distances are reduced and the gain leads to P_R'.

Once implemented on a department or single team, the effect can be taken to the next organizational level. Given all the already existing gains within the groups, also the consciousness between groups rises. This effect is dependent on the already existing development within the teams. Teams can now exploit the already existing outputs of the tools, i.e., the knowledge maps, in order to know better about the other teams. If conducted throughout critical parts of the organization, the benefit of the individual adaptation can be maximized as a between team adapted action benefit A_D:

$$A_D = \sum_{t=1}^{n} \sum_{i=1}^{p} \Delta e_{t.i}$$

In order to visualize the effect, the schema in Fig. 14.2 would need 3-dimensional stacking. If the tools help in narrowing the gap of understanding in such a way, all effort will be visible in the profits directly. Companies have to pay for the labor and infrastructure whether or not the people who conduct the projects use tools properly (or at all) to narrow down the gaps. To simplify things, projects are reduced to have just a single goal and only depicted with two participants in the figures. Usually projects have more participants and multiple goals. The effect may increase above linear when the project goals are not discrete to each other. If the project goals have intersections of expertise or are linked in any other than a pure sequential way, then the benefits in A_B will easily become exponential. Then of course the effect stacking (Fig. 14.2) would have more than three dimensions.

3.3 Summary

A meeting or discussion usually ends when everybody has the impression of a plausible, mutual understanding. But in fact, a real matched understanding is rare (up to impossible). This essential problem is both a strength and a weakness of human language (Vygotskij & Kozulin, 1997) and cannot be avoided by any technique, no matter how well communication habits may be. Thus, in regular discussions, the undiscovered misconceptions lead to different assumptions about current states and goals of a given problem (e.g., a project). The differences between the assumptions lead to different decisions, while the different decisions lead to different outcomes that may even contradict each other in parts. The result is always loss of work—when everybody is working towards a different direction. Additional methods to support discussions cannot completely circumvent these gaps, but they can narrow them down. Methods that narrow down such gaps need to focus on the misconceptions in a constructive way—so that being wrong is perceived as shortcoming of the discussion rather than of any of the coworker. If misconceptions are discovered in early decision-making stages of work processes, i.e., in initial meetings, they do not need to unfold “the hard way,” i.e., by errors and mistakes in or—even worse—after the work process. The result is a process that leads to goals more efficiently, thus minimizing the labor, time, and costs within or throughout medium to large, central, or high-risk projects. Both the process and the outcome will benefit from reaching out towards a general knowledge strategy (Wenger, 2004).

4 Automatically Generated Knowledge Maps

In this paper, a tool is shown to reduce the gap of misunderstanding. The tool relies on knowledge maps that are created from text. Knowledge maps in particular utilized towards the goal of narrowing down gaps between different understandings. They are applied in many practical applications throughout different companies. After a training phase and customization, they can improve meeting efficiency as well as transfer in the work process itself. Real evaluations and cases are however rarely published. The contents usually touch the core processes of the companies, and therefore they always demanded nondisclosure agreements so far.

Knowledge maps can be created in many different ways and with different technologies. Expectedly, automatically created knowledge maps may have qualitative disadvantages when compared to manually created knowledge maps. But this has never been investigated. However, they provide a very economic trade-off should the resources not allow to construct manual ones (Pirnay-Dummer & Ifenthaler, 2010). Creating a proper knowledge map by hand usually takes many hours and expert interviews in the field. The costs span not only the researchers who construct the knowledge maps within the working environment of the company but also the time of the experts. Depending on the goals and resources, it may be helpful to decide for an automatically created knowledge map. Algorithms from the semantic web can be a good choice if many thousand documents on the same topic are available (Pirnay-Dummer, 2012). But the creation of a real ontology has also labor intense phases, especially when the domain is very specific and no ontologies are available at the start (Pirnay-Dummer & Walter, 2009). Thus, this chapter introduces a technology that is based on already existing and tested methods from knowledge assessment and uses it to heuristically create knowledge maps from text corpora of companies. The methodology uses the original algorithms from T-MITOCAR (*T*ext-*M*odel *I*nspection *T*race *o*f *C*oncepts *a*nd *R*elations; see Pirnay-Dummer & Ifenthaler, 2010) and expands them to the *T-MITOCAR Artemis* technology that creates knowledge maps from many documents.

4.1 How Artemis Maps Look Like

Most knowledge maps have a mind-map-like structure. They contain concepts, sometimes statements, figures, and facts, and its parts are linked in some way, preferably by relations. Knowledge maps may also contain substructures like encapsulated or embedded structures. The automated knowledge maps used in these projects with the companies are networks of complex associations.

Figure 14.3 shows an example of an Artemis Map. In their original format they have colors that represent different parts of the knowledge to be represented. Each color resembles a different field, domain, department, or work process. The intersections of the model areas may help the participants to identify and use interfaces between the different kinds of expertise more easily and move their thought back and forth through the attached fields. How this clustering is conducted depends on the input in each case, and the users can influence the areas directly based on the documents they attach to each field.

4.2 How Artemis Maps Are Created

From newly developed methodology and technology for knowledge assessment come computer linguistic heuristics that create association networks from prose text without further encoding (Pirnay-Dummer & Ifenthaler, 2010) (Fig. 14.4). In the original version of the software, T-MITOCAR algorithms are stable at aggregating multiple sources to one association map if the contents are of the same area.

The aggregation works in the same way as within HIMATT (Highly Integrated Model Assessment Technology and Tools, Pirnay-Dummer, Ifenthaler, & Spector, 2010) and AKOVIA (Automated Knowledge Visualization and Assessment, Pirnay-Dummer & Ifenthaler, 2010). Several sources can be aggregated with the T-MITOCAR algorithm if they cover a similar content, e.g., if they cover the same domain (see Fig. 14.5).

Figure 14.6 shows the whole process from the aggregation of the sets of documents to the combination of the models onto an Artemis Map. Instead of using just one graphical representation, T-MITOCAR Artemis creates many of them and integrates them into one graphical visualization. The integration shows every single source model in a separate color. The term flexions are stemmed (word stems) and normalized throughout the integrated visualization to one word function so that, for instance, plurals and singulars would be treated as one term.

The maps are created by using prose texts that already exist within the documents of the company. No additional formatting is needed and also no additional texts need to be written, and neither the texts nor the graphs need any manual attention throughout the process.

While the text-based methods for knowledge assessment need a careful selection of the right content and comparison (Pirnay-Dummer, 2010; Pirnay-Dummer & Ifenthaler, 2010; Pirnay-Dummer et al., 2010), the creation of a knowledge map needs far less control. The quantity of the documents available from the linguistic corpus of a company helps the algorithms to reduce the inhomogeneity between the concepts and relations and thus crystalize the core patterns of a knowledge structure

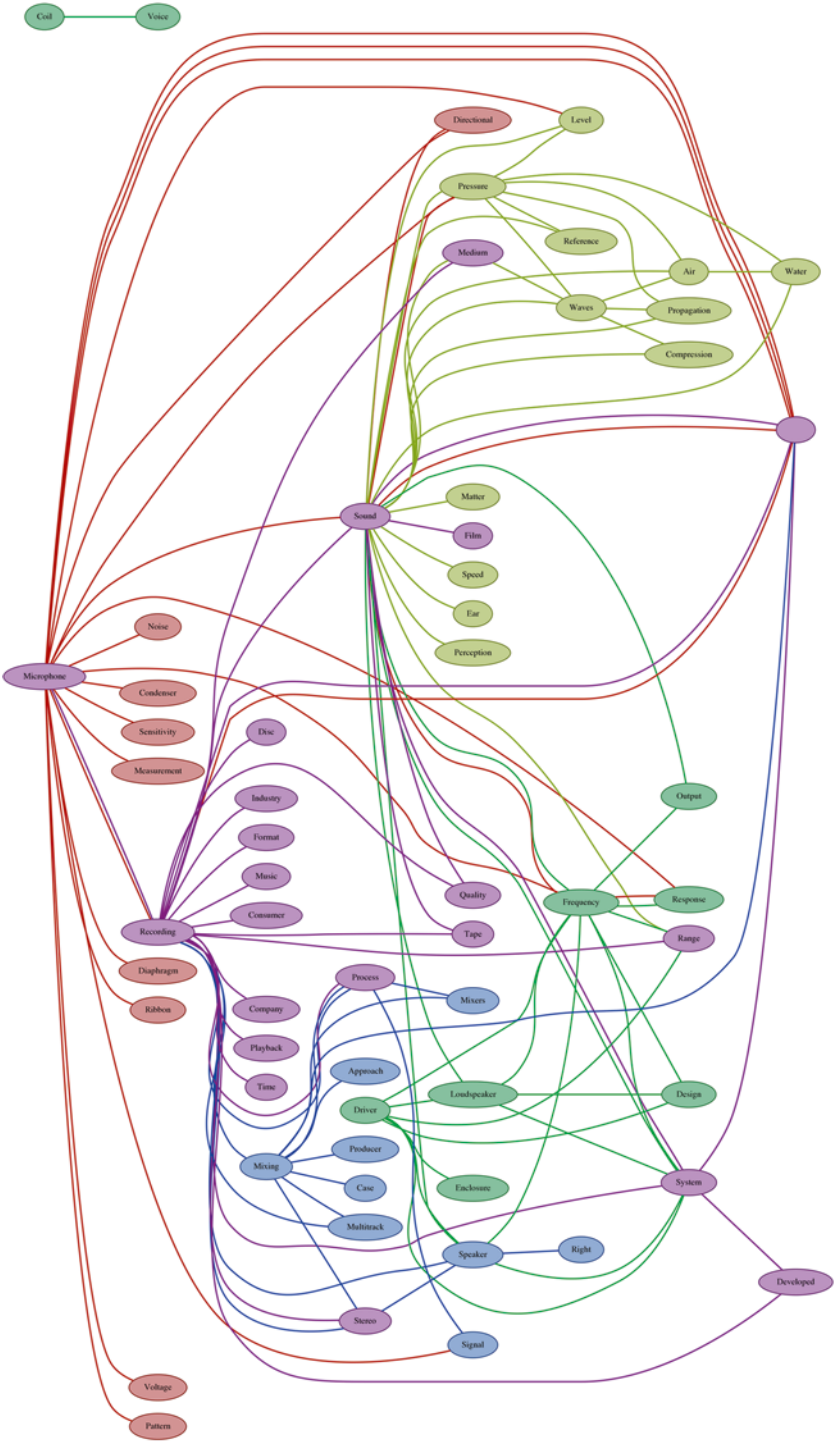

Fig. 14.3 Example of an Artemis map

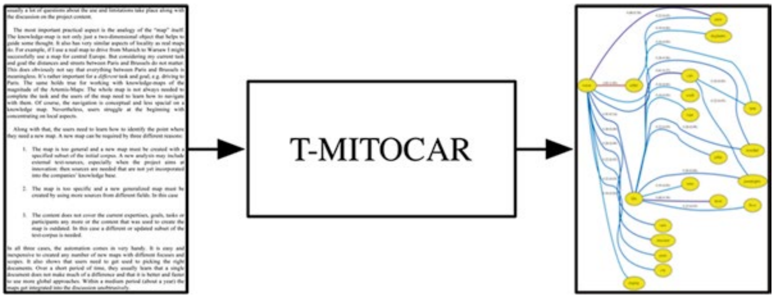

Fig. 14.4 T-MITOCAR association net from a single document source

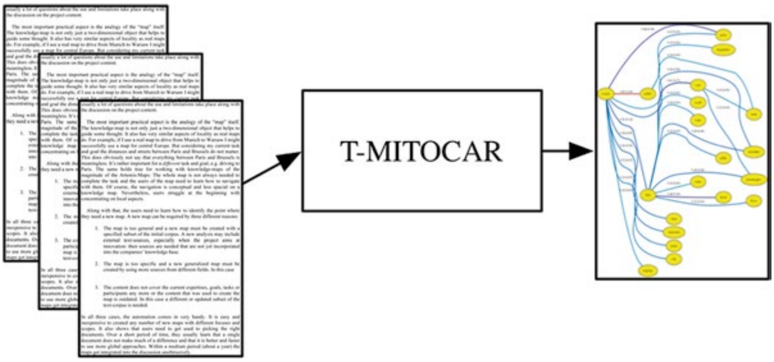

Fig. 14.5 T-MITOCAR aggregation of several documents on the same domain

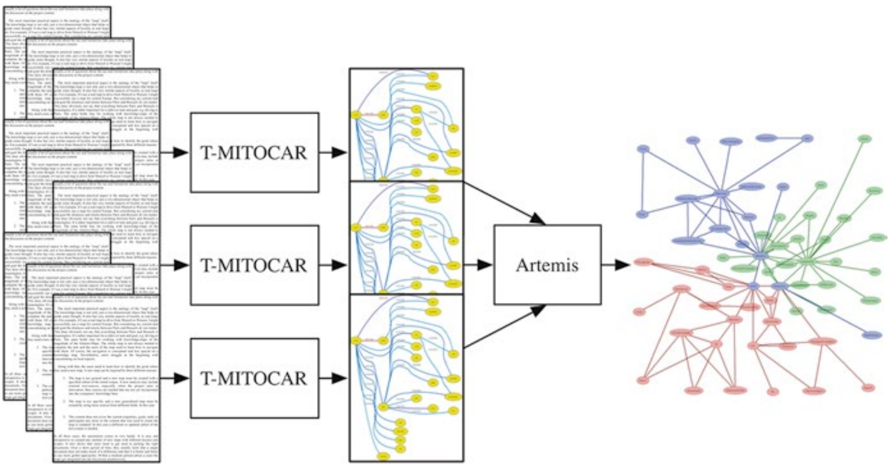

Fig. 14.6 Artemis aggregation of domains onto a knowledge map

encoded in the text. In most companies, text documents are already there—content that does not need to be produced. The knowledge map algorithms of Artemis can exploit the already existing text basis with no further encoding.

4.3 What Information Artemis Maps Contain

But what does using the already existing documents allow for? The texts are already there. Why can't the participants just read them? There are two answers to that. First, there are usually too many texts in order to read them all to get an overview. Aggregation is necessary. One could of course have dossiers on a field. The problem with them is not so much the required labor but the way of the aggregation: the aggregation to a dossier is created by a single person—or by a small group. If it is not the whole group who creates the dossier then all the initially mentioned problems of misconception will occur again: it is the mental representation of the individual or small group that decides on the aggregation and the others will have to rely on the compatibility of their thought to that representation. However, this is the initial problem that required tools like knowledge maps in the first place. Thus, secondly the validity and objectivity of the aggregation needs to be controlled in order to produce external artifacts (like knowledge maps) that help to guide the misconceptions. In other words, automated knowledge maps are faster, less expensive, and a priori more valid and objective than accessing and aggregating the contents by hand.

Automated knowledge maps created by Artemis contain different fields that are connected and help guiding the conversation of the participants to the aspects (e.g., the interdisciplinary interfaces between domains), which they do not yet sufficiently understand. They contain concepts and their relations. Both are derived from any selected corpus from the company and may be complemented by any external texts that play a role in the process (e.g., reviews, audits, legal texts, requirements, operating procedures).

4.4 Keywords from Creating Artemis Maps

As a side gain, the Artemis methodology also fetches the most model-relevant concepts from a text corpus. Although they intersect with the most frequent terms, the list of model-relevant words is not the same. The aggregation process results in a list of terms that are central for the model. The Artemis algorithm has shown promising results at the task of identifying keywords, e.g., for document management systems (DMS).

A fixed sequence of processes completes the list of keywords (see Fig. 14.7). First, a fitting text corpus is selected. This may cover all of the documents or parts of it depending on the scope of the keyword index to be created. Essentially all kinds of documents that need to be indexed afterwards are required for the analysis.

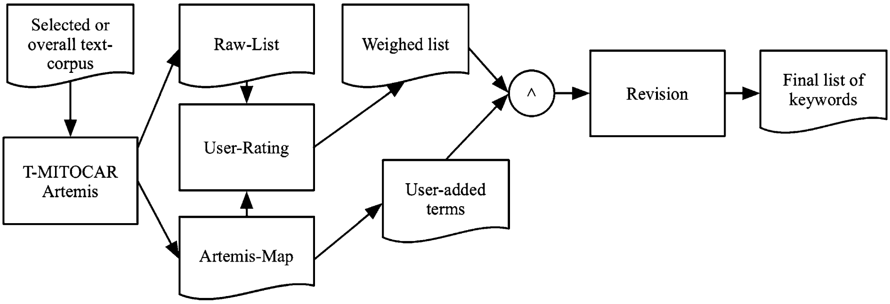

Fig. 14.7 Identifying keywords with the help of Artemis

The documents may come in subclusters to address different fields. From the clusters an Artemis Map is created. During the process, a raw list of terms is also created. Ten to twenty users then rate the raw list. The top-ranking terms of the weighted list may be expanded by key users who may add terms at that point. The resulting list is revised and validated by experts who give clearance for the final list. The whole process is transparent to all the users because an Artemis Map is also created to visualize the underlying model that leads to the terms. The map can be annotated during rating and revision.

5 Application

Knowledge maps have a spatial advantage over other methods aiming at misconceptions (e.g., moderated discussions, specific documentation): it allows direct pointing and interaction in a way that somebody can literally follow an idea or reasoning path. Automated knowledge maps are however not constructed by the group—unlike mind maps, for example. Members of the group will first have to learn how to use the conceptual maps. If the group manages to select the right clusters of documents for their task, they will have a knowledge map that supports understanding throughout all project phases, not only within meetings or other direct conversations.

5.1 Learn How to Use Them

Despite their later-on practical use, which may be completely integrated into the discussion processes, the use of Artemis Maps and also the use of knowledge maps have to be trained with all the participants. In some rare cases, a culture of use may sustain the integration of new group members. Hence, in very experienced groups no further training may be needed.

Training starts with briefly introducing example maps by inductively showing how misconceptions can be resolved by using them. Then, a real map from the companies' corpus is created and discussed. At this point, the discussions need to be moderated by an expert on knowledge maps, and usually a lot of questions about the use and limitations take place along with the discussion on the project content.

The most important practical aspect is the analogy of the "map" itself. The knowledge map is not only just a two-dimensional object that helps to guide some thought. It also has very similar aspects of locality as real maps do. For example, if a real map is used to drive from Munich to Warsaw, one might successfully use a map for central Europe. But considering the current task and goal, the distances and streets between Paris and Brussels do not matter. This does obviously not say that everything between Paris and Brussels is meaningless. It's rather important for a *different* task and goal such as driving to Paris. The same holds true for working with knowledge maps of the magnitude of the Artemis Maps: The whole map is not always needed to complete the task, and the users of the map need to learn how to navigate with them. Of course, the navigation is conceptual and less spatial on a knowledge map. Nevertheless, users struggle at the beginning with concentrating on local aspects.

Along with that, the users need to learn how to identify the point where they need a new map. A new map can be required for three different reasons:

1. The map is too general, and a new map must be created with a specified subset of the initial corpus. A new analysis may include external text sources, especially when the project aims at innovation: then sources are needed that are not yet incorporated into the companies' knowledge base.
2. The map is too specific, and a new generalized map must be created by using more sources from different fields.
3. The content does not cover the current kinds of expertise, goals, tasks, or participants any more or the content that was used to create the map is outdated. In this case a different or updated subset of the text corpus is needed.

In all three cases, the automation comes in very handy. It is easy and inexpensive to create any number of new maps with different focuses and scopes. It also shows that users need to get used to picking the right documents. Over a short period of time, they usually learn that a single document does not make much of a difference and that it is better and faster to use more global approaches. Within a medium period (about a year), the maps get integrated into the discussion unobtrusively.

5.2 Applying Artemis Maps in Projects

Once the users are trained to apply the Artemis Maps to their discussions and meetings, applying them is quite easy. Artemis Maps should be printed out in a large format, visible at a central spot for every meeting, and easily accessible simultaneously by multiple participants. It is advised against printing the maps on a regular sheet of paper. Instead, they should be printed in large format (like construction plans would) and in color. Otherwise the information of the different knowledge domains would be lost. For further discussion, it is necessary that all users use the same physical object as the map—as opposed to everybody using his or her own version of the map. To spot misconceptions, pointing and a common object view is needed. During discussions it is often necessary to annotate the maps. If many annotations are made, it may come in handy to laminate the maps. If annotations are made, the maps should be digitally photographed in a sufficient resolution to refer back to the annotations later on.

The map should be present even at meetings where the map is not used. Not every meeting or every decision in the progress requires using the map, but the group should have access to it at any time. The group also needs a person responsible for keeping and updating the map if necessary. Outside of the meetings, project directors have been observed who put a printed version of the map on their wall to return to the map whenever they make project decisions.

During discussions, the map should be used mainly to discover additional misconceptions between or within expertise. The participants can ask for parts of the model, which they don't understand. But the better way would be for specific experts to explain relevant parts of the maps from time to time thus creating the opportunity for others to recognize parts of the language use or thought that are unaligned.

If a group is rather new at using the maps, then a moderator may help to identify and locate the current problem, task, direction, or goal on the map to help the users find their way. In experienced groups, such a moderator will not be necessary—depending on the topic, someone usually takes this role for the duration of a single argument. Most of the above-mentioned experiences are generic to using knowledge maps in meetings and can be applied to knowledge maps that have been built in a different methodological way.

The use of the maps and their costs should be tracked. With the automated Artemis Maps, the effort is easy to track. The use of the maps can also be used within knowledge balance sheets if the company uses them in order to quantify aspects of the knowledge for internal or external use. The original technology (Pirnay-Dummer & Ifenthaler, 2010) contains powerful indicators to compare knowledge regarding its structure and semantics. The indicators can also be used on Artemis Maps, e.g., to track the change (or rate of change) of the maps over time and thus identify processes of high and low knowledge development (by change) over time.

6 Discussion

The Artemis Methodology creates knowledge maps within or between domains by using available documents only. The resulting knowledge maps are neither better nor worse than many other artifacts created by means of different methods. What makes them interesting for practice is their ease of construction and the very fast production process. This opens up practical possibilities to explore both general and specific uses within working processes and projects. The main achievement within meetings and other project work is to reduce the level of unnoticed misunderstanding. The project work gets more aligned and focused which raises efficiency and reduces effort, first in labor and then in the resources spent on the effects from inefficient decisions.

Like using real maps, the use of knowledge maps needs to be trained. And the instructors conducting the training need to know the theoretical and methodological limitations in depth in order to help the practitioners to sort out which conclusions can be made and which cannot be made by using the knowledge maps. Knowledge maps are after all just one tool among many others. It takes some time for the users to balance between the "magic bullet" and the "nonsense" impressions the first steps with using the knowledge maps may have.

As understandable as the nondisclosure agreements are, they also create a shortcoming for research. Plenty of real cases exist, but they can rarely be published, especially regarding content. It stands to hope that there will be such cases and examples from open projects in the future, which could even be used as an advertisement by the companies for their strength in management—although it is unfortunately not very likely based on the author's experiences. This introduction into the technology and its use was shown despite of considerable shortcomings. On the other hand, it is simple to try the methods. After all, it is not very costly to create the maps and to use them in projects.

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Chapter 15
Digital Concept Mapping for Formative Assessment

Heiko Krabbe

Abstract Concept maps are widely used as assessment tool in research projects but do not seem to be often used for diagnostic purposes in school practice. Their evaluation is regarded to be too time consuming and of lower reliability compared to written tests. Therefore, different computer-based approaches are reviewed which have the opportunity to improve the reliability and to reduce the effort of evaluation. Their options for formative assessment on an individual and class level are discussed with the intention to foster achievement through diagnostic feedback. Finally, ideas how to enhance the available software solutions are derived. For this chapter especially research on digital concept mapping published in the German language has been reviewed in order to make this body of knowledge accessible to the international community

Keywords Digital concept mapping • Structural and semantic measures • Formative assessment • Visual analysis • Modal maps

1 Introduction

Feedback to teachers on achieving the learning intentions they have for their students is amongst the most powerful effects for improving instruction and increasing the learning outcome of the students (Hattie 2009, p.181). One such form of feedback is formative assessment that provides individual data about the students or average data about the whole learning group. Teachers would have to evaluate and reflect students' activities and then use this information to further adapt instruction.

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Concept maps drawn by students might be an appropriate way to diagnose their knowledge structures. They do not need much preparation, and at a first glance it seems that they are easy to assess. A review of research on concept mapping shows that they are used in various ways in the international scholarly community. While their use as a learning aid that helps to structure knowledge is widely accepted, it is often questioned whether they are a useful and reliable assessment tool. Ruiz-Primo and Shavelson (1996) summed up and illustrated a multifaceted picture of how and in which way concept maps are used for assessment in research. They concluded that three properties characterize concept maps—the task format, the response format, and the scoring system—as well as exposed the huge variability each of these properties can have. In the same manner as tests with different answer formats (e.g., multiple-choice, short answers) and scoring systems measuring different aspects of knowledge, these varied concept mapping methods can generate distinct representations of knowledge. Reviewing German research on concept mapping, Peuckert and Fischler (2000) also pointed out that concept maps with specific forms of task format, response format, and scoring system measure characteristics of knowledge that cannot be perceived with other methods, like tests. Results on convergent validity of concept maps compared to other methods are, therefore, considered to depend specifically on task formats and scoring systems (Schecker & Klieme, 2000, p.47). Therefore, it is not remarkable that results in research concerning reliability and validity of concept mapping are not consistent (amongst others see McClure, Sonak, & Suen, 1999; Ruiz-Primo, Schultz, Li, & Shavelson, 2001; Ruiz-Primo & Shavelson, 1996). However, for the purpose of formative assessment in school practice, the didactical relevance of the diagnosis and its impact on instructions is more important than the accuracy of the diagnosis. It would be acceptable if teachers diagnose their students less precise, provided that teachers are aware of this and conduct diagnostics regularly in order to correct their diagnosis and to adjust their instructions (Helmke, 2009, p. 129).

2 Assessment with Digital Concept Maps

2.1 Task Format

There exists a wide range of concept mapping tasks which may lead to different conclusions about students' knowledge (Ruiz-Primo, 2000; Ruiz-Primo & Shavelson, 1996). In her recent overview, Strautmane (2012) distilled the seven most frequently used concept mapping tasks. Three of them are so-called fill-in-the-map tasks with a predefined structure and either predefined concepts or relations. The task is to fill in left-out concepts or relations which may be chosen from a provided list. These high-directed task formats are considered to activate student's knowledge rather than to represent their knowledge structure (Ruiz-Primo et al., 2001). They can be seen as an alternative to a fill-in-the-text test. The other four frequent task formats are so-called construct-a-map tasks. Their commonalities are that there is no constraint to the structure. They can be characterized by their conditions for the concepts and relations which define three levels of directedness (Ruiz-Primo, 2000):

(a) *High-directed*. A complete list of concepts and a complete list of linking words for the relations are provided either with or without distracters. Distracters are misleading concepts that indicate misconceptions if they are wrongly integrated in the concept map.
(b) *Low-directed*. Only a complete list of concepts (usually without distracters) is provided.
(c) *Not-directed*. Nothing is provided.

Often elaborated linking phrases are regarded as a feature of deeper understanding and expertise (Kinchin, 2000). These of course can only be observed for a low-directed or not-directed task format. In the high-directed task format, the quality and variety of linking phrases is preset, and only correctness can be considered (see Table 15.1). Some attempts have been made to define general linking types and categories of linking words instead of content-specific linking phrases [examples are Ballstaedt et al. (1989); Bonato (1990); Dansereau et al. (1979); Fischler and Peuckert (2000) in Table 15.1].

Ruiz-Primo et al. (2001) showed for low-directed construct-a-map tasks that they could reveal the conceptual understanding of students better than fill-in-the-map tasks. The construct-a-map task required more content knowledge and was overall more challenging. The following sections will concentrate on construct-a-map tasks only as these seem to be more useful for formative assessment.

2.2 Response Format

For instructional purposes, concept maps can be drawn with paper and pencil or generated with computer software. According to Royer and Royer (2004), students prefer using a computer instead of paper and pencil and even create more complex concept maps with the computer. This higher complexity of the maps is not only an expression of more meaningful learning (Novak & Gowin, 1984), but it also enables a more elaborative formative assessment.

Schanze and Grüß-Niehaus (2008) described the use of computer-generated concept maps with 13–15-year-old students as learning tool in chemistry courses. They emphasized that computer-based concept maps can more easily be revised than paper and pencil maps and thus provide a benefit for the development and correction of conceptions through progressive concept mapping. As possible drawbacks, they mentioned the need to train students in using the specific computer software and infrastructural requirements. Another hindrance at school is insufficient computers for all students, which could be overcome by using dedicated computer rooms or asking students to bring their own computers. Therefore, they advised to use

Table 15.1 Provided linking words or linking types of different studies

Dansereau et al. (1979); Lambiotte et al. (1989)	hierarchical structure				cluster structure	Chain structure		
	static		Instructional		Static	dynamic		
	part	type	example, comment	analogy	characteristic	influence, leads to, next		
Ballstaedt et al. (1989)	hierarchical structure		cluster structure			chain structure		
	part-whole relation: is part of, is section of	"is-a" relation: is a type of, is an example of, is kind of	confirmation-relation: denotes, confirms, verifies	analogy-relation: is similar to, is equivalent to is like	attribute relation: has, is attribute of is feature of	causation relation: causes, leads to, generates		
Bonato[a] (1990)	part-whole relation	term-subterm relation	example	equality relation	attribute	implication		
Weber (1994)	definition component					cause and effect: leads to, is necessary for manipulation:	mathematical expression	specific verbs: has the goal to, decides, gets, is responsible for, has the right to,
	consists of			is equal or equivalent to				
Fischler, Peuckert[b] (2000)		subterm: is a			attribute: has, features	activity token: does, causes	functional relation: determines	plain assignment: has to do with
Eckert[c] (2000) Study 1		is always (subtopic, example) is usually,		is synonym of, is compliment to				is used in/by
Eckert[c] (2000) Study 2	is part of		is an example of	is equal to, is compliment to	is attribute of	avoids, acts on, act together		
Stracke (2004)	is part of	is a			describes qualitatively	is condition for, increases, affects, affects not,	describes quantitatively, can be calculated with	further eight content specific linking phrases were provided

[a]Concepts were written on cards which could be grouped to indicate a listing (logical and relation)
[b]To each of the five categories also a negated and a potential relation was built, e. g., for subterm: is *not* a, is *possibly* a
[c]Participants were allowed to assign multiple categories to a link and to create their own text

software with a web interface or client-server architecture that allows to retrieve a concept map from different work places through the Internet. This also enables to complete concept maps in homework and collaborative work.

A digital response format also enables an automated evaluation of concept maps which will be described in more detail below. This gives the opportunity to enhance learning by several cycles of progressive concept mapping with more or less automated feedback from formative assessment.

2.3 Scoring System

From the broad variety of scoring systems, we will focus on those that can be supported by an automated evaluation of digital concept maps. Ruiz-Primo and Shavelson (1996) suggested a major distinction between scoring strategies that score components of the students' maps and those that compare the students' map with a reference map. In the case of automated evaluations, another discrimination that results in similar classes of scoring systems differs between structural and semantic analysis of concept maps (Ifenthaler, Masduki, & Seel, 2011).

The choice of a particular scoring system is not independent from the choice of the task format and response format. Restrictions to the allowed concepts or relations might be necessary if it is to be compared with a reference map. On the other hand, even within the same task format, different scoring methods may measure different aspects of a domain (Rice, Ryan, & Samson, 1998).

2.3.1 Scores for Components

By treating a concept map as a graph, many structural measures can be derived from graph theory (Bonato, 1990; Costa et al., 2007) and social network analysis (Borgatti & Everett, 2005). Examples are listed in Table 15.2.

Using appropriate algorithms (Brandes & Erlebach, 2005), these measures can easily be calculated for digital concept maps. The question, however, is how these quantitative measures can be related to the quality of the knowledge and understanding that is represented in the concept maps.

The first question is whether the concept map can be treated as a directed graph. Often the direction of links in the concept map must be neglected because it has no reliable meaning. For example, the relation "a battery provides electric current" could easily be stated in the inverse direction (electric current is provided by a battery) if students can choose their own linking words. Undirected graphs unfortunately neglect any logical hierarchy of the concepts.

Secondly, single graph theoretical measures only provide a summative score without any conclusive interpretation. Using a set of several measures instead, it

Table 15.2 Measures from graph theory

Measure	Explanation
Centrality measures for a single vertex of a graph (vertex level)	
Degree	Number of edges connected to a vertex or equally the number of directly connected vertices
Closeness	The distance of two vertices is the length of the shortest path between them. The closeness is the average distance of a vertex to all the other vertices
Betweenness	Counts how often the vertex is part of the shortest path between all the other vertices
Hoede status score (Hoede, 1978, Bonato, 1990)	A generalized degree that takes additionally the weighted indirect neighborhood to all the other vertices into account
Measures for the whole graph (graph level)	
Size	Number of vertices: n
Complexity	Number of edges: k
Density	Average number of edges per vertex: k/n (equivalent to the average vertex degree)
Link density	Number of edges divided by the maximal possible number of edges: $2k/(n(n-1))$
Diameter	The largest distance between two vertices of the graph
Compactness	Average of the distances between all vertices. Higher values indicate a lower compactness
Relative maximal path length (RMPL)	The maximal path length divided by the maximal possible path length or equally: RMPL = diameter/$(n-1)$ For RMPL = 1 the graph is a single chain and for RMPL = 1/$(n-1)$ the graph is a star
Ruggedness	Number of components. Components are disconnected parts of a graph
Closed walks	Number of cycles. A cycle is a path of length greater than two that ends at its starting point
Diameter of the spanning tree	A spanning tree is a representations of the graph where all cycles are eliminated by deleting selected edges. Thus canceling shortcuts between vertices the diameter of the spanning tree can be larger than the diameter of the graph

must be noted that they are not independent because they are all functions of the number of vertices and edges. To illustrate the use of these measures, three German studies are now presented:

1. Bonato (1990) investigated the classification of 98 knowledge networks of high-school students (age 16–20) and undergraduate university students (age 19–27) using a set of structural measures. He used a kind of low-directed construct-a-map task format where the students had to extract their own concepts from an information text first. With these, they had to construct a concept map then characterizing the relations between the concepts with a limited set of six relation types (Table 15.1). Thus the directions of the links were well defined so that the maps could be treated as directed graph. In order to classify the maps through a cluster analysis, Bonato (1990) first built groups of equivalent measures with an

explorative factor analysis and selected representative measures. This should ensure that the variables in the cluster analysis are not highly correlated. As a result, he used only four different measures: *compactness* of the directed and undirected graph, the *RMPL* of the undirected graph (as substitute for the diameter), the *ruggedness* (number of components), and the correlation of the *Hoede Status Scores* with those of a reference map (see Table 15.2). (The last measure actually is a kind of structural matching as described below.) These measures allowed him to distinguish four different clusters of knowledge networks. Cluster 2 was described as the compact and well-structured networks with low *RMPL* and high *Hoede-overlap*, whereas cluster 1 was the opposite. Cluster 3 was characterized by a higher number of components, while cluster 4 had the lowest numbers of components, but high values for *compactness*, indicating a more chain-like structure. Cluster 2 and 4 had a relative high number of vertices compared to cluster 1 and 3. Bonato (1990) compared these results with an independent quality rating of the maps. The maps of cluster 2 and 4 got significantly better marks than those of cluster 1 and 3. Differences within the two groups were not significant although maps of cluster 2 got throughout the best results. In contrast to that person scores built from a knowledge test and IQ tests could not separate between the clusters.

2. Friege and Lind (2000) tried to relate the extent, quality, and structure of the area-specific knowledge of experts to their area-specific problem-solving abilities. They had participants which were enrolled in a physics course in either the final high-school year or the first year at university as well as attendees of the high-school competition *International Physics Olympiad*, which they divided into groups of 51 beginners, 26 novices, and 31 experts according to their performance in an initial problem-solving test. The participants had to draw a low-directed construct-a-map task with 17 provided concepts but no restrictions to the relations. Not all provided concepts had to be used and additional concepts could be added, but that was rarely done. The concept maps were treated as undirected graph neglecting also the labels of the nodes (vertices) and links (edges). As structural measures, they used the *size*, the *linkage*, the *density*, and the *ruggedness* (see Table 15.2). In order to distinguish a chain-like, treelike, and network-like structure, they defined two additionally measures: (1) the *number of vertices with degree one* and (2) the *number of central vertices with degree higher than three*. The threshold of three was chosen arbitrarily according to the distribution of degrees in their sample. With these they found in their sample 11.1 % chain-like maps where all nodes had a degree below the threshold, 7.4 % treelike maps with only one node beyond the threshold, and 81.5 % network-like maps with several nodes above the threshold. Comparing the groups of expertise Friege and Lind (2000) reported significant differences in all of their six structural measures. The maps of experts showed more vertices and edges, a higher *density* and less unconnected components. They also described a tendency of fewer chain-like maps and more network-like structures with increasing degree of expertise, but had to admit that already 72.5 % of the novices drew network-like maps. They explained this

with their choice of concepts, which supported multiple relations. Providing more concepts with a topic-subtopic relation, they would have expected more treelike structures. Nevertheless, their two self-defined measures showed the best variance between the groups. Measures like the *size* and *density* were less discriminating. They were very much influenced by the task format because the participants tried to use all of the provided concepts. Friege and Lind (2000) compared all six structural measures with a knowledge test, too, reporting correlation values in the range of 0.331–0.616. Yet, it should be noted that almost all measures were pairwise significantly correlated.

3. Ifenthaler et al. (2011) investigated the development of cognitive structures calculating the structural measures *size*, *complexity*, *density* (average vertex degree), *diameter of the spanning tree*, *ruggedness*, and *closed walks* (see Table 15.2) of concept maps which were treated as undirected graphs. The measures had been proved to be retest reliable (e.g., $r=0.824$ for the *complexity* and $r=0.815$ for the *diameter of the spanning tree*) and valid first (Ifenthaler, 2010a). Twenty-five students from university (mean age 24.7) were asked to construct a not-directed concept map at five measurement points in time during a course on research methods. The course learning outcome was also rated according to written assignments, exams, and research proposals. All measures except the *density* revealed a significant growth along the measurement points. They interpreted this as an accommodation process (Piaget, 1976) because the students continuously added new concepts (*size*) and links between concepts (*complexity*) to their cognitive structure and created more elaborated maps (increasing *diameter of spanning tree* and *closed walks*) throughout the learning process. From the significant growth in *ruggedness*, they concluded that newly learned concepts are not immediately integrated into the cognitive structure. In contrast, the learning outcome only correlated significantly with the *density* ($r=0.58$) and the *closed walks* ($r=0.51$) of the maps at the last measurement point.

Summing up, it is possible to describe concept maps by a set of structural measures in order to track their development over time or to distinguish different types of knowledge structures. Mostly measures for the whole graph are used together with tasks formats of less directness where greater differences in size, diameter, etc. can be expected. The graph is usually assumed to be undirected. It seems necessary to combine multiple structural measures although they are quite correlated. A big drawback is that the different structures of concept maps cannot be connected with the quality of the maps' content in a singular and straight way. Since the map structure is influenced by the concept map task and content, only some general heuristic rules for the quality of a map can be given. The correlation of structural measures to external knowledge indicators like tests is ambivalent. Furthermore, structural measures only give summative scores with little semantic information and are thus not suitable for formative assessment. Only the ranking of concepts due to centrality measures may provide diagnostic information. Such rankings can be built on an individual or a group level.

2.3.2 Comparison with a Reference Map

According to Ruiz-Primo and Shavelson (1996, p. 595) *scoring criteria that focus more on the adequacy of the propositions* should be superior to those *that focus simply on counting the number of map components.* Using a scoring system that judged the selection of the necessary concepts and the correctness of the link between them, Rice et al. (1998) did yield remarkable high correlations from $r=0.44$ to $r=0.74$ for the concurrent validity with a multiple-choice tests but emphasized that a good match between the scoring system and the construct to be measured is critical for that. Therefore, reference maps can be used both as a good starting point for defining the construct to be measured and as reference point for an automated scoring of correctness.

For the automated evaluation reference maps can be used in two ways. One can be seen as an extension of the previous structural analysis and can be called *structural matching*. It compares the structural measures of a student map with the structural measures of a reference map, still neglecting the labels of the nodes and links. The similarity s between the student map S and the reference map R on any structural measure m can be calculated as

$$s = 1 - \frac{|m_S - m_R|}{\max(m_S, m_R)}.$$

It can take values between $s=0$ (complete exclusion) and $s=1$ (identity) (Ifenthaler, 2010b). The advantage of the similarity value is that the influence of the topic or the chosen concepts on the structure of the maps is eliminated.

The other method includes the labels of the nodes and links in some way and can be called "*semantic matching*" (Ifenthaler, 2010b). For the conceptual matching, it is simply the set of concepts of a student map that is compared with the set of concepts in the reference map. The combination of two concepts and the link between them is called a proposition. Propositional matching can be examined differently depending on the task format. For a not-directed or low-directed task format, the linking words between two concepts are mostly too diverse. In that case, propositions in a student map and a reference map are often considered to be equal if there is just a link between the same concepts, omitting the linking words and direction of the link. High-directed task formats additionally offer the opportunity to require for identical propositions which means that the linking words and the direction of the link expected to be the same in the student and reference map.

Of course the absolute value of agreement between two maps depends on the size of the maps. Therefore normalized measures are useful. Bonato (1990) defines the overlap measure o of two maps A and B with respect to a property-set P (e.g., set of concept, set of propositions) as

$$o = \frac{|P_A \cap P_B|}{|P_A \cup P_B|},$$

while Ifenthaler (2010b) suggests the Tversky similarity measure (Tversky, 1977)

$$s = \frac{|P_A \cap P_B|}{|P_A \cap P_B| + \alpha |P_A \setminus P_B| + \beta |P_B \setminus P_A|}.$$

With the parameters α and β, the similarity measure allows balancing different sizes of the maps, for example, when comparing an extensive reference with a smaller student map. This might be necessary if the students only used a subset of a provided concept list because of task instructions or a time limit. The parameters can also be used to adjust the similarity measure to the amount of disagreement between the maps. In case of $\alpha = \beta < 1$, the disagreement is undervalued and in case of $\alpha = \beta > 1$, it is overvalued. For $\alpha = \beta = 1$, the similarity measure is identical to the overlap.

Ruiz-Primo (2000) introduced a convergence score, which is "the proportion of accurate propositions in the student's map out of the total possible valid propositions in the criterion map" (expert's map), and a salience score, which is "…the proportion of valid propositions out of all propositions in the student's map" (Ruiz-Primo, 2000, p. 37). These correspond to the propositional similarity with $\alpha = 1$ and $\beta = 0$ for the convergence score and $\alpha = 0$ and $\beta = 1$ for the salience score if A is the reference map and B is the student map. From her studies, she concluded that such scores "can consistently rank students relative to one another and provide a good estimate of a student's level of performance, independently of how well their classmates performed" and that the convergence score "seems to better reflect systematic differences in students' connected understanding and is the most effort and time efficient indicator" (Ruiz-Primo, 2000, p. 47).

Ifenthaler (2009) also used a balanced propositional matching. This is the proposition similarity of two maps (with $\alpha = \beta = 0.5$) divided by the absolute number of shared concepts.

Specially for propositional matching, a correspondence coefficient c between a reference map A and a student map B can be calculated as

$$c = \frac{w_1 P_{\bar{A}\bar{B}} + w_2 P_{AB} - \left(w_1 P_{\bar{A}B} + w_2 P_{A\bar{B}}\right)}{w_1 \left(P_{\bar{A}\bar{B}} + P_{\bar{A}B}\right) + w_2 \left(P_{A\bar{B}} + P_{AB}\right)},$$

where $P_{\bar{A}\bar{B}}, P_{A\bar{B}}, P_{\bar{A}B}, P_{AB}$ is the sum of corresponding concepts that are not linked in both maps, only linked in map A, only linked in map B, or linked in both maps, respectively (Eckert, 2000). For the simple correspondence coefficient, the weights w_1 and w_2 are set to one. The weighted correspondence coefficient additionally sets

$$w_1 = \frac{P_{A\bar{B}} + P_{AB}}{P_{\bar{A}B} + P_{\bar{A}\bar{B}}} \text{ and } w_2 = \frac{1}{w_1}.$$

This is taking into account that correct links in the student map are of higher significance if the reference map is sparsely linked, whereas for a highly linked reference map it is more important to find accordance in the missing links. It also balances whether a student is likely to establish many links, thus having a higher chance to hit correct links, or setting links reluctantly. The correspondence coefficient can take values between $c = -1$ (complete exclusion) and $c = 1$ (identity). It should be noted that the correspondence coefficient is only reasonable if the student map uses the same concepts as the reference map or a subset of them. Otherwise the number of not linked concepts increases artificially due to missing links between the additional student concepts and the concepts of the reference map.

Structural and semantic matching has the common problem of obtaining a suitable reference map. In most instances, an expert map is used, which defines the optimal representation of the knowledge domain that should be achieved by the students. It should consist of propositions that are considered to be "substantial" to the domain and that students should know about a topic at a particular point (Ruiz-Primo, 2000, p. 38). This as described by Ruiz-Primo (2000) requires a procedure where several experts first provide lists of important concepts and reach a consensus about the most important concept. Then, they have to draw concept maps with these concepts and agree on the relations that should be included in the final reference map. Since concept maps from experts can be rather different (Acton, Johnston, & Goldsmith, 1994), it is suggested to use only relations that appear in at least 80 % of the individual expert maps. However, such a laborious process is hardly applicable in school environments. Often, teacher will simply create their own reference map based on their instruction, a textbook analysis or the curriculum.

The next section will discuss three German investigations in greater detail. The first two use a high-directed concept map tasks and the last one a not-directed task:

1. Eckert (2000) conducted two studies in which he compared structural scoring with semantic matching. In both he used the *link density* and *ruggedness* as structural measures (see Table 15.2) and three variants of the *weighted correspondence coefficient*. The first variant c_{w1} considered the propositions to be without label and direction, the second c_{w2} used the labels but not the directions, and the third c_{w3} used both. In the first study, 32 university students were asked to fill-in a learning strategy survey, use a hypertext learning program about cost and activity accounting, and finally to draw a concept map about that topic. The high-directed concept map task format provided 20 concepts and 5 general linking words (see Table 15.1) which were also used by two experts (one of them the author of the hypertext course) who built the reference map together. With a learning strategy survey, it was possible to differ between *metacognition, critical checking*, and elaboration techniques like *repetition.* The students' concept map measures showed for the *link density* and the *correspondence coefficients* c_{w1} and c_{w3} very similar significant correlations in the range of $r = 0.24$ to $r = 0.36$ with the learning strategies *metacognition* and *critical checking* from the survey, but no correlations for *repetition*. For the *ruggedness*, no correlation with any learning strategies appeared, and the *correspondence coefficient* c_{w2} revealed an unexpected behavior with no correlation for *metacognition* but the highest correlation ($r = 0.41$) for *critical checking*.

   Eighteen participants had also been asked to draw a concept map in advance. On the one hand, no training effects from the concept mapping could be observed, but on the other hand the quality of the pre-maps explained much more the quality of the post-maps than the learning strategy did.

Thus, in a second study, the sensitivity of the concept maps to changes in the knowledge was tested with 11 participants aged between 18 and 25 (10 fifth-year university students and 1 high-school student). They had to draw a high-directed concept map, work through an information text, and then again draw the concept map. As topic functional kinetics was chosen because it does not need much preknowledge and specially focuses on the relations between physiological entities. Fourteen concepts and eight relations (see Table 15.1) were selected from the information text by three experts who commonly created the reference map. As results, a significantly higher *link density* and lower *ruggedness* were found in the post-maps which indicated more elaborated concept maps. In the same manner significant enhancements in the *correspondence coefficients* c_{w1}, c_{w2}, and c_{w3} proved a growth of the correct knowledge. All three *correspondence coefficients* behaved equally.

2. In order to define a reference map for the topic of chemical equilibrium Stracke (2004) went through the previously described extensive process of Ruiz-Primo (2000). She advised to also include members of the target group into that process in order to optimize the fitting of the reference map. At the end of that process, she devised 16 concepts and 17 relations for a high-directed task format, with 9 relations of a more general kind and 8 content-specific relations (see Table 15.1).

   In her investigation on computer-based concept mapping, Stracke (2004) distributed first-year university students who were enrolled in chemistry as major or minor subject into an experimental group ($n = 54$) and a control group ($n = 53$). The control group filled in a background survey and constructed an initial concept map on the first day. The following day, the same students were asked to construct the concept map again and to give a personal review about the computer-based concept mapping. In addition, the experimental group participated in a web-based lecture about chemical equilibrium (30 min finishing the first day and 30 min starting the second day) and a pre and post knowledge test. Both groups received concept mapping training at the beginning of the study. For analysis, Stracke (2004) used the *complexity* and *ruggedness* (see Table 15.2) as structural measures and the *non-weighted and weighted correspondence coefficients* c_3 and c_{w3} as semantic matching. In the control group, she found a test-retest reliability in the range of $r = 0.75$ to $r = 0.78$ for all the measures. Nevertheless, there was a significant change for the structural measures but not for the semantic measures between the initial and the final map in this group. The increase of *complexity* and decrease of *ruggedness* without learning phase was explained by a training effect in using the concept mapping software. Thus Stracke (2004) interpreted the results as clear evidence that concepts maps are stable enough in time in order to assess achievement. In contrast, the experimental group showed significant improvements related to achievement in all four measures. Although the change of *complexity* and *ruggedness* exceeded that of the control group, Stracke (2004) argued that only the semantic matching measures showed reliable differences between both groups. Further analysis showed that students in the experimental group constructed more than 50 %

new propositions in the post-map, while students in the control group mainly constructed identical propositions in both maps. Also, the concurrent validity with the knowledge test was evaluated. For the pretest, all four measures correlated significantly (absolute values between $r = 0.52$ and $r = 0.68$). Significant correlations were also found for the posttest, but the correlations for the structural measures decreased while they remained the same for the semantic matching.

The knowledge test was constructed in such a way that it was possible to typify the knowledge in the two dimensions *kind of knowledge* (factual, conceptual) and *cognitive process* (remember, understand, apply) (Anderson & Krathwohl, 2001). In the pretest significant partial correlations of the *complexity* measure and both *correspondence coefficients* with *factual knowledge* were observed in the pretest, but in the posttest only significant partial correlations of the *correspondence coefficients* with *conceptual knowledge* were found. In the same way, the pretest showed significant partial correlations of the *complexity* measure and both *correspondence coefficients* only with the *application of knowledge*, while in the posttest solely significant partial correlations of the *correspondence coefficients* with *understanding* were observed. Such differences between pre- and posttest suggest that preknowledge is a key factor. With little preknowledge, concept maps seem to assess the ability to apply factual knowledge. In contrast with extended knowledge, they seem to reveal conceptual understanding. Stracke (2004) concluded that the assumption that concept maps only assess high-order cognitive abilities cannot be supported. Likewise, it cannot be said that a high-directed task format simply tests the recall of factual knowledge. Furthermore, semantic matching (specially the *weighted correspondence coefficient* c_{w3}) proved to be suitable for comparing student maps with a reference map and to be superior to structural measures.

3. In the investigation of the development of cognitive structures that was already described in the previous section, Ifenthaler et al. (2011) additionally used the Tversky similarity measure (with $\alpha = \beta = 0.5$) in order to calculate the conceptual matching and propositional matching. Unfortunately, it is not reported how the reference map was constructed and whether the labeling and direction of the links was taken into account. The retest reliability of the similarity measures has been checked in a preceding study [$r = 0.901$ for propositional matching (Ifenthaler, 2010a)]. For their not-directed task format, they found a significant growth in the *conceptual similarity* but not in the *propositional similarity*. In accordance, the learning outcome only correlated significantly with the *conceptual similarity* ($r = 0.42$). Thus they concluded that the students became more familiar with the terminology of the subject domain, which enables them to communicate their cognitive structures more precisely and in a more expert-like manner.

As expected, the automated comparison with a reference using either similarity or correspondence measure (correctness of knowledge) proves to be superior to the scoring of components (organization of knowledge). Analyzing the retest reliabilities measures for semantic matching were found to be more stable (over a period of a few days) than structural measures independently from the task format. Thus, they are more sensitive to the impact of intermediate learning processes. Thereby it does not seem to matter much whether the labeling or the direction of the relations are included into the analysis or not. Differences between the task formats were found in the elicited knowledge structure. The reduction of ruggedness indicates a consolidation of knowledge when a fixed amount of concepts is given, whereas the increase of (not necessarily integrated) knowledge can be observed if concepts can be chosen freely. Equally propositional matching seems to be more sensitive in the first case, while conceptual matching shows considerable changes in the latter case. Moderate correlations of semantic matching measures with other indicators for learning achievement confirm a reasonable concurrent validity in both cases, although the question still remains whether these instruments elicit the same kind of knowledge. In the same manner the influence of the preknowledge and the reference map on semantic matching measures needs further investigation.

Like the structural measures, the values for the structural and semantic matching merely deliver summative information about a student's performance. For formative purposes it is necessary to investigate the differences between a student map and the reference map with regard to the content in more detail. Based upon the assumption that a person sets in a concept map links consciously without guidance from the task, a wrong link should indicate a relatively stable wrong perception. Therefore, Stracke (2004) proposed to identify misconceptions automatically by comparing student maps with a reference map that consists of typical wrong propositions. She first derived from the misconception literature two such typical wrong propositions in the topic of chemical equilibrium. Each defined a misconception map that consisted only of a single wrong proposition. She then calculated the *weighted correspondence coefficient* c_{w3} for the student maps compared to the misconception map. The existence of the wrong proposition in a map would result in a value of +1 and in a −1 otherwise. Using a reference map with the correct proposition instead, this method can equally be applied to search for the correct conception. Thus Stracke (2004) was able to quickly identify those students who set the correct, wrong, or no link between the concepts under consideration. For the experimental group, she found in the pre-maps on average about 18 % correct, 10 % wrong, and 72 % missing links. This changed to 71 % correct, 1 % wrong, and 28 % missing links in the post-map. In contrast a comparable distribution in the pre-maps of the control group remained in the post-maps. These findings were validated for one of the misconceptions with a corresponding item of the knowledge test. Persons who set the correct proposition almost never got the item wrong, but often left it out. From those who set the wrong proposition, only one identified the item correctly while the majority skipped it. If the proposition was missing in the concept map, the person sometimes got the item right, but mostly omitted it too.

2.4 Visual Analysis

Formative assessment can be supported by special computer-generated representations of digital concept maps that enable a qualitative visual analysis. Depending on the software, different features can be used which allow an analysis either at an individual level or at an aggregated group level. In the following section, some examples will be given.

2.4.1 Individual Level

Lüthjohann and Parchmann (2011) reported the use of visual analysis during the implementation of a new science curriculum in grade 5 and 6 at German secondary schools. Their software allowed only concept maps with a high-directed task format. Students had to select their concepts and linking phrases from administered lists. For the visual analysis, their software offered to display multiple individual concept maps at the same time. It was possible to reposition single concepts in order to gain a clearer arrangement or even to automatically order all concepts according to their position in a reference map. This simplified the visual comparison of different concept maps. Visual analysis was used for (1) the planning and reflection of instruction and (2) the evaluation of individual learning achievement. Lüthjohann and Parchmann (2011) created for each unit of their curriculum a target map that could be used as reference. For the planning of their instruction, they analyzed from preceding concept maps how many students of their classes already indicated certain aspects of a topic as preknowledge. This enabled them to adapt their instruction. Equally, at the end of a unit they analyzed the final concept maps in order to explore for which content areas their unit had already worked and where improvement was still necessary. Comparing visually, the initial and final concept map of a student reveals the individual learning achievement. In addition, automatically generated difference maps (map of new and skipped propositions) could help to investigate the learning process (Peuckert & Fischler, 2000). To analyze the remaining knowledge gaps, the final map could be visually compared with the unit target map. All these methods can be employed for formative self-assessment of the students too.

Ifenthaler (2009) investigated three different types of automatically generated visual feedback. In his study, 74 university students (average age 21.9 years) had to construct a not-directed concept map. Then, they received a text on climate change together with automatically generated feedback information. After that, they again constructed a not-directed concept map. The students were randomly assigned to three experimental groups. In the first group (*cutaway feedback*), they received as feedback their original concept map with those concepts highlighted that were part of an experts' reference map. The *discrepancy feedback* for the students in the second group consisted only of propositions from their original concept map that had no semantic similarity to the experts' map. The third group (*expert feedback*) was offered a standardized re-representation of the expert model. Four automatically calculated structural matching measures (comparing the *complexity*, the *density*, the *diameter of the spanning tree*, and a *complete structure trace* with the expert map) and three semantic matching measures (*conceptual matching*, *propositional matching*, and *balanced propositional matching*) were used in order to elicit changes in the participants' understanding of climate change. Significant changes could be found for three structural matching measures (the *complexity,* the *diameter of the* *spanning tree*, and a *complete structure trace)* with the best similarity gain for the *expert feedback* and the least for the *cutaway feedback* in each case. Obviously, the expert map provided the strongest guidance to assimilate to the structure of the expert map. In contrast, there was only a significant change for the *conceptual matching* as semantic measure. Here, participants getting *cutaway feedback* performed better than in the *discrepancy feedback* or *expert feedback* groups. Hence, assimilating to the structure does not necessarily mean that the correct concepts are used. Again for the not-directed task formats, the selection of concepts seems to matter most. However, it is not quite clear from the publication if and how the labeling and the direction of the relations were taken into account. This might explain the weak results for *propositional matching* and *balanced propositional matching*.

2.4.2 Group Level

In order to assess the shared knowledge of a learning group, Weber (1994) introduced the construction of an average concept maps called modal map. Weber's main idea was to define an order of the propositions according to their relevance for the learning group and a threshold for the inclusion of the most relevant propositions into the modal map. Since students might use different linking phrases between two concepts, she distinguished between propositions and concept pairs. Concept pairs are vertex-edge-vertex combinations that in opposite to propositions neglect the linking phrases. Weber (1994) considered concept pairs to be more relevant for the learning group the more frequently they occur in the students' concept maps. Since there could be many concept pairs with the same frequency, this ordering was not sufficiently determined. Therefore, within groups of equal frequency, she additionally weighted the relevance of concept pairs with respect to the size of the concept maps in which they occurred. Concept pairs used in smaller concepts map were regarded to be more representative for the group than those used in larger concept maps. This was done by adding the inverse number of concept pairs of the maps in which a concept pair was found. Concept pairs of equal frequency were ranked according to the value of this sum. For example, a concept pair that appeared in three maps consisting of 27, 34, and 40 concept pairs ($1/27+1/34+1/40=0.091$) would be ranked lower than a concept pair that appeared in three maps with 30, 31, and 35 concept pairs ($1/30+1/31+1/35=0.094$). Weber (1994) defined the *cut point* for the number of concept pairs to be included into the modal map by the average number of concept pairs in the concept maps of the learning group. This is the total number of concept pairs over all student maps divided by the number of maps. After selecting the concept pairs for the modal map, these could be annotated with the different linking phrases used by the students in the corresponding propositions. Thus the number of student propositions represented by the modal map is usually much higher than the number of concept pairs. Therefore, Weber (1994) defined the *representation power* of a modal as quotient of the number of represented propositions divided by the total number of concept pairs over all student maps.

Table 15.3 Descriptive data of modal maps

	Experimental group		Control group	
	Pre	Post	Pre	Post
Total concept pairs	793	764	880	980
Number of students	19	19	21	21
Cut point	42	40	42	47
Represented propositions	176	201	206	251
Different propositions	94	111	131	137
Representation power	22.2 %	27.5 %	23.4 %	25.6 %

Weber (1994) used modal maps in order to compare the preknowledge and the knowledge development of two classes at a vocational business school. One class (experimental group) was trained with a computer-based management game. The other class (control group) received ordinary instruction. The students were asked to draw concept maps with a high-directed task format prior to and after the intervention. In a pre-study, 65 concepts and 15 linking phrases (see Table 15.1) had been selected that on the one hand were typical for the knowledge of her students and on the other hand covered the relevant parts of business management so that the students would not be constricted to elaborate the offered concepts. Table 15.3 gives the descriptive data of the modal maps.

The *representation power* increased for both groups (control group + 9 %; experimental group + 24 %). This indicates that the knowledge became more homogeneous. Like for the individual maps, the content of the modal maps can be analyzed visually. This revealed qualitative differences between the two groups. Although both groups showed manifold relationships between different business parts, the level of argumentation in the experimental group was found to be higher. The experimental group was more likely to use "cause-effect" relations and "specific verbs" than the control group, which used more "component" relations and general "manipulation" relation (see Table 15.1) in a descriptive manner. On the other hand, only the experimental group showed an imperfect understanding of the business cycle which indicated a deficit of the intervention with the management game.

Once modal maps are created, they can be analyzed in the same way as individual student maps. For example, they could be compared with a reference map in order to reveal major misconceptions in a class. But the use of modal maps is not without controversy. The question is whether a modal map really represents the average knowledge of a group. Often due to the cut point, even propositions are included that are not used by the majority of the group. Weber (1994), for example, had to include concept pairs of frequency 3, which means that only about 3/20 = 15 % of the students drew these connection. But there seem to be no fundamental alternative for the generalization of individual maps (Peuckert & Fischler, 2000). Some variations of the original method have been proposed. (e.g., Behrendt, Dahncke, & Reiska, 2000; Fürstenau & Trojahner, 2005; Fürstenau, Trojahner, & Oldenbürger, 2009). Their major concern is to find a better selection of propositions that is more representative for the group of students. In our own research, we did not use the cut point but defined a threshold as the minimum percentage of the student maps in

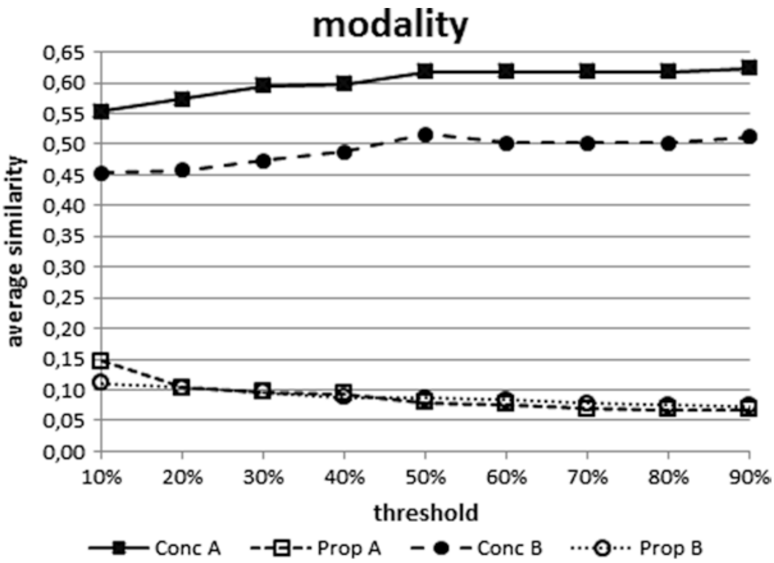

Fig. 15.1 Conceptual and propositional matching between student maps and the modal maps for the two task formats

which a proposition had to appear in order to be included into the modal map. This threshold was increased from 10 to 90 % in steps of 10 %. Propositions were only treated as concept pairs. To judge the quality of the resulting modal map, we considered its modality (representativeness) and its validity. Therefore, we calculated the conceptual and propositional matching between the student maps and the modal map based on the Tversky similarity measure with $\alpha=\beta=0.5$ (see Sect. 15.2.3.2). The average of these matching measures over all students was used as indicator for the modality, whereas the correlation of these measures with the results of a competency test was taken as an indicator for the validity. The concept maps and the competency test were conducted in an investigation of four physics classes at grade 9 of a German secondary school ($N=74$) (Ley, Krabbe, & Fischer, 2012). We split each class into half and used two different task formats. Task format A was low-directed and offered a list of 26 words around the core concept of energy. Students had to choose at least ten words for the concept map. In task format B, the students first received only three pictures relating to energy. After 15 min, they too were given the word list and asked to make additions. This can be regarded as a nearly not-directed task format. In order to get reasonable modal maps especially for task format B some unification of the used concepts (e.g. potential energy = position energy) had to be done manually.

Concerning modality (Fig. 15.1), the average conceptual matching is acceptable for a threshold above 50 % for both task formats and values are higher for task format A. The average propositional matching is for both task formats very low. It increases slightly with the increasing size of the modal maps at lower thresholds. The validity (Fig. 15.2) also increases for more extensive modal maps. It is

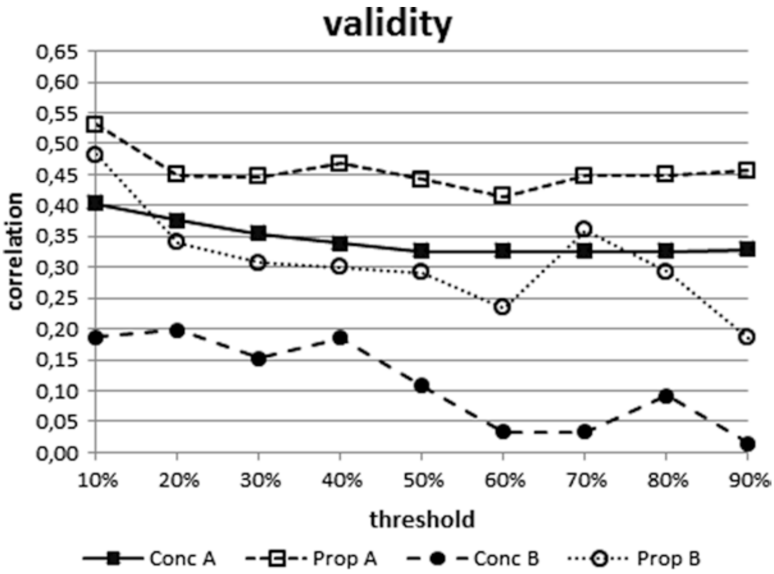

Fig. 15.2 Correlation of the conceptual and propositional matching of the students maps with the competency test

obviously higher and more stable for task format A. Conclusions are that a threshold of 50 % would be a good compromise between an acceptable modality and validity. Values are better for the more directed task format A. We also found that it was easier for the students to show their abilities in the competency test than in our concept mapping tasks. Although they had training in concept mapping beforehand, this technique seemed to be more challenging for them.

3 Conclusion

Using an automated evaluation of digital concept maps, there is no concern about the objectivity and reliability of the scoring necessary. The retest reliability of computer-based concept mapping has been established in several studies independently from the task format. Also, the correlation with other assessment instruments (mostly tests or exams) has widely been proven, but it is still under question whether they elicit comparable kinds of knowledge. Therefore Fischler and Peuckert (2000) advised not to rely solely on concept mapping as assessment tool unless it is better understood what kind of knowledge it reveals.

Most of the reviewed studies have been conducted with university students. Thus it is still an open question whether concept mapping is suitable for assessment at middle and high school. It seems as if high-directed task formats which provide both concepts and linking phrases have some advantages for that purpose:

1. Although often challenged high-directed task formats can assess high-cognitive abilities, they even seem to account better for the correctness of the propositions than less restricted task formats do, which seem to be more sensitive to the selection of the important concepts.
2. Especially for an automated evaluation, they offer the opportunity to consider a consistent set of linking phrases that can be related to certain types of connections (see Table 15.1).
3. If too diverse concepts and linking phrases are used due to less directing task formats, it is more difficult to compare concept maps of students and to built a reasonable modal map. A manual unification of the concepts and linking phrases might be necessary.
4. Providing a certain amount of concepts and linking phrases, the assessment might be better focused on the desired information. It is still possible to regulate the constriction by the amount of concepts and the flexibility of the linking phrases. If, for example, a large number of concepts (e.g., 60) are provided, students can be asked to select only a smaller amount (e.g., 15) for the construction of their concept map.
5. It is assumed that more directing task formats are easier to use for students, because they might reduce cognitive load. Thus, they could be a better fit for students at middle and high school.

Obviously, further basic research is essential in order to clarify the best choice of the task format in dependence of the target group and assessment goals.

To make formative assessment with digital concept maps accessible, it is crucial to provide appropriate and easy to use software solutions. There are several free and proprietary software products available that allow the construction of concept maps. (For an overview, see Wikipedia, 2012.) Software that is particularly dedicated for concept maps may also offer some evaluation features. In general, evaluation features are yet quite rudimentary, and sometimes they impose restrictions on the possible task format.

Currently, we know only two software solutions that support formative assessment. One is MaNet (2012) which was developed by Eckert (2000) and later used by Stracke (2004) and Lüthjohann and Parchmann (2011). This software is restricted to high-directed concept mapping only. In contrast the other available option, AKOVIA (or rather HIMATT which includes a user interface to construct digital concept maps), cannot force participants to use specific concepts or linking phrases. AKOVIA has been developed by Pirnay-Dummer and Ifenthaler (2010) and was used for our research (Ley et al., 2012). Both software solutions offer the automated calculation of a variety of structural and semantic measures and the generation of graphical representations like modal maps that can be used for a visual analysis. They were both implemented for research purposes and of course have their pros and cons, most likely needing enhancements to be useful for formative assessment at school. Helpful features are:

- An administration of learning groups which provides single accounts for each student but also enables the shared development of concept maps

- Graphical representations that support the comparison of individual student maps with a reference map, for example, by aligning the concepts accordingly or highlighting differences and similarities
- A graphical representation of modal maps that annotates the edges with the linking phrases that occurred and their frequency
- The search for specific propositions in order to identify proper or misleading conception in the learning group
- Assistance for a supplementary unification of the occurring concepts and linking phrases according to synonyms and relation categories

With the software provided further research will be necessary in investigating how formative assessment with digital concept maps can be performed at school, how teacher will accept and use the tool, and if students receive such kind of diagnostics as beneficial. The key question is whether digital concept maps can fulfill the expectation to foster students' learning achievement through diagnostic feedback.

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Chapter 16
Digital Knowledge Maps: The Foundation for Learning Analytics Through Instructional Games

Debbie Denise Reese

Abstract The CyGaMEs (Cyberlearning through Game-based, Metaphor Enhanced Learning Objects) approach to instructional game design and embedded assessment provides a formalism to translate domain knowledge into procedural gameplay. As such, CyGaMEs learning environments are transactional digital knowledge maps that make abstract concepts concrete and actionable: translating what experts know into procedures learners do (discover and apply). CyGaMEs produces games designed to provide viable prior knowledge as preparation for future learning. After knowledge specification through a task analysis, the method applies cognitive science analogical reasoning theory to translate targeted learning goals into game goals and translate targeted knowledge as the game world (e.g., rules and core mechanics). The CyGaMEs approach designs gameplay parameters as the Timed Report measure of player performance to quantify and trace trajectories of learning and achievement. The approach is one way to address design for alignment and shortcomings and limitations documented in the literature that plague current learning game design, embedded assessment, and research. Chapter discussion introduces the national initiative for cyberlearning and embedded assessment and insights from evidence-centered design and cognitive tutor development practices, especially regarding task analysis and cognitive task analysis. Then CyGaMEs' *Selene: A Lunar Construction GaME* design artifacts, screen captures, gameplay data, and analyses illustrate this approach to design and embedded assessment. A case is made that instructional game design with embedded assessment is an enterprise requiring complex expertise among teams of professionals—topped by talent and creativity.

Keywords Task analysis • Timed Report • Learning analytics • Instructional games • CyGaMEs

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1 Introduction

Seeing. Hearing. Touching. Humans process a cacophony of sensation through perception and cognition.

The transactions of day-to-day living require selective attention that filters for salience. After attending,[1] people interpret new experience by what they already know. Prior experience and knowledge help people to interact with and learn from current experience. Occasionally, experience is so new that people must start fresh, building new cognitive structures of mapped relations. Relevant experience, especially expertise, facilitates learning. Novices lack experience and expertise. This means a novice lacks the cognitive structures that guide attention to salient information. They also lack cognitive structures for assimilation, for viably constructing new knowledge from old. Learning is difficult when people lack apt prior knowledge. This is where instruction comes in. A key principle underlying instructional design is prior knowledge activation (Merrill, 2002). When learners lack relevant prior knowledge, instruction should provide experiences that serve as prior knowledge to anchor the "to-be-learned."

In this chapter I give an example of how game-based learning environments can be designed as analogs of targeted abstract knowledge to ready learners for knowledge construction. Acting as transactional, concrete models of knowledge maps, these CyGaMEs (Cyberlearning through Game-based, Metaphor Enhanced Learning Objects) instructional games guide learners to discover and apply the relational structure of targeted knowledge. CyGaMEs environments are performance-based assessments that measure learner progress. This is a measure of preparation for learning. The chapter begins with a review of the literature about prior knowledge and knowledge specification (especially performance-based computer assessment). Then I use the CyGaMEs environment *Selene: A Lunar Construction GaME* and research data to illustrate how the CyGaMEs approach conducts knowledge specification and translation for instruction and assessment.

CyGaMEs assessment is a form of learning analytics. Knowledge specification through task analysis produces knowledge maps (ontologies). Each ontology constrains and directs game design and assessment. As I will explain and illustrate using *Selene*, CyGaMEs takes an a priori approach to learning analytics. A CyGaMEs approach quantifies player gameplay behavior to measure learning.

1.1 Relevant, Concrete Prior Experience

Robert Gagné (1965) explained that learners must master fundamental principles if learning is to be meaningful rather than "parrot[ed] verbal sequences" (p. 185).

[1] Attention is both a top-down and bottom-up process. Thus, it is also informed by prior knowledge (e.g., expectations). For example, a face in a crowd might stand out due to resemblance to a close friend.

"If adequate principles are to be learned later," relevant sensory experience (e.g., oncrete transactions with an environment) is of "great importance to instruction in all subjects" (p. 184). The to-be-learned must be "relatable to quite concrete stimulus situations" (p. 184). Daniel Schwartz and Taylor Martin (2004) coined the phrase "preparation for future learning" to describe interventions and processes that ready learners for knowledge acquisition (or the more active descriptor, knowledge construction).

Concrete, lived experience provides powerful preparation for future learning. Instructional games can be designed to provide just that type of lived experience, gameplay that serves as concrete prior knowledge to prepare learners for acquisition of targeted knowledge. Such game worlds (e.g., mechanics, rules, and goals) must be designed and developed to guide and reinforce learners to discover and apply targeted concepts. Ideally, game worlds provide only salient sensory input. Game goals and feedback guide, reward, and scaffold transactions that model the relational structure of the targeted knowledge. Thus, they can be designed to involve the learner in problem solving to construct conceptual knowledge and fundamental principles (for problem solving to construct principles, see Gagné, 1965; for conceptual knowledge, see Jonassen, 2006). Instructional games that meet this requirement are actually concrete relational analogs of targeted domains. They are transactional, digital knowledge maps[2] that serve as a source domain for making perceptually based observations of relational structure. As mathematician Polya (1954) noted, "Experience modifies human beliefs. We learn from experience or, rather, we ought to learn from experience. To make the best possible use of experience is one of the great human tasks" (Polya, 1954, p. 3).

1.2 Designing Game-Based Learning to Support Induction

Design and development of these games require relational specification of the to-be-learned domain and then translation of that specification as the transactional game environment. CyGaMEs is a formal approach for instructional game design and development. The CyGaMEs approach prepares students for future learning by translating targeted relational structure of conceptual knowledge (what is invisible inside experts' heads) into procedural gameplay (what learners do). When relevant experience anchors new knowledge, learning is more intuitive. This is because the game guides and rewards player observations, subsequent transactions, and problem solving through successive trials of a process Polya described as plausible reasoning (1954). More technically stated, induction infers a conjecture that is provisional, but not necessarily true. "Anything new we learn about the world

[2] Within this volume digital knowledge maps are defined as "at a glance" visual representations that enable enriching, imaginative, and transformative ways for teaching and learning, with the potential to enhance outcomes.

involves plausible reasoning" (p. v). This is the stuff of induction and analogical inferences (Richland, Stigler, & Holyoak, 2012).

Analogical inferences are "ubiquitous in human reasoning and [provide] a basis for the induction of complex relational knowledge such as schemas and rules" (Hummel & Holyoak, 1997, p. 427). Polya (1954) identified three inductive processes: generalization (inferring from a given set to a larger set), specialization (inferring from a set to a smaller, subsumed set), and analogy ("inference when two systems agree in clearly definable relations of their respective parts," p. 13). Polya's nonmathematical example of analogy compared relational mappings among a man's hand, a cat's paw, a whale's fin, a bat's wing, and a horse's foreleg. Polya observed, "Analogy seems to have a share in all discoveries, but in some it has the lion's share" (p. 17).

Scientifically, as in real life, conjectures are judged on the basis of observable consequences (Polya, 1954, p. 22). For the scientist this is an inductive attitude. In CyGaMEs gameplay each successive trial during which a player manipulates the world to move closer to a game goal is a small analogy. Each time the game world behaves according to the mapped relational structure for the targeted knowledge domain, the player has observed and accrued an additional confirming consequence in response to an embodied transaction. And this is exactly why instructional game analogs must map accurately to the target domain. When game worlds mismap to targeted knowledge, each successive trial reinforces the mismapped content. If a misaligned game succeeds as a game, the player learns the content well, but wrong.

1.3 Embedded Assessment Within Cyberlearning Environments

The CyGaMEs design process leverages the data-driven nature of game-based technologies to measure learning as the player progresses through the game. A CyGaMEs instructional environment is a performance-based assessment that measures and reports player behavior. The sequence of data reports over time forms a player's learning trajectory. CyGaMEs assessment is embedded within authentic practice. CyGaMEs measures learning while it occurs.

Recognizing potential for instructional games to enhanced teaching and learning by meeting individual needs through personalized instruction, federal agencies such as the Department of Education and the National Science Foundation incorporated instructional games with embedded assessment within their initiatives and plans (e.g., Borgman et al., 2008; U.S. Department of Education Office of Educational Technology (ED), 2010). The Department of Education, specifically, recommends (p. xvii).

- *Research and development that explores how embedded assessment technologies, such as simulations, collaboration environments, virtual worlds, games, and cognitive tutors, can be used to engage and motivate learners while assessing complex skills.*

- *States, districts, and others should design, develop, and implement assessments that give students, educators, and other stakeholders timely and actionable feedback about student learning to improve achievement and instructional practices.*
- [The nation should] *build the capacity of educators, education institutions, and developers to use technology to improve assessment materials and processes for both formative and summative uses. Technology can support measuring performances that cannot be assessed with conventional testing formats, providing our education system with opportunities to design, develop, and validate new and more effective assessment materials. Building this capacity can be accelerated through knowledge exchange, collaboration, and better alignment between educators (practitioners) and experts.*

The nation's education technology plan (Borgman et al., 2008) supports a future in which cyberlearning environments provide assessment and evaluation through learning analytics (Bienkowski, Feng, & Means, 2012). This chapter describes how the CyGaMEs approach to instructional game design uses knowledge maps to guide and constrain instructional game design and learning analytics. Targeted examples from the CyGaMEs flagship environment, *Selene: A Lunar Construction GaME* (http://selene.cet.edu), illustrate knowledge map specification and data analytics. *Selene* players ages 9 and older discover how the Earth's Moon formed and evolved over time. They construct the Moon and then pepper its surface with impact craters and flood it with lava flows as they replicate its 4.5 billion year history. *Selene* aligns to the new science education framework (Committee on Conceptual Framework for the New K-12 Science Education Standards & National Research Council, 2011, see alignment specification at http://selene.cet.edu/?page=educators&state=National-Framework) and core concepts (Next Generation Science Standards Team, 2012).

2 Knowledge Specification

2.1 Formal Approach Required

One branch of related contemporary cyberlearning environments can be conceptualized as four major categories: cognitive tutors, simulations, instructional games, and virtual worlds. In practice these categories are not mutually exclusive; any one environment may incorporate features from more than one category. So, a cognitive tutor might incorporate gaminess, and a game might incorporate one or more simulations within a virtual 3-D world.

The Carnegie Learning Cognitive Tutor mathematics software personalizes practice and remediation by adaptively guiding students through problem solving on the fly. The cognitive tutor derived from artificial intelligence research modeling human cognition through ACT-R (Adaptive Control of Thought-Rational, originally ACT, i.e., Anderson, Corbett, Koedinger, & Pelletier, 1995; Anderson & Lebiere, 1998). Specification of the to-be-learned knowledge domain is essential and core to development of a cognitive tutor and the instruction it supports. According to John R. Anderson and Christian D. Schunn, the cognitive tutor design and development process begins with "extensive task analyses" through which the scientists develop "cognitive models" of targeted knowledge and skills (2000, p. 19). Task analysis ensures alignment between targeted knowledge and the tutor. Anderson and Schunn consider accurate task analysis and alignment essential to the power of the cognitive tutor. Indeed, the task analysis becomes the foundation of a cognitive tutor's design and development. In fact:

- Accurate cognitive task analysis is the most time consuming component of developing the cognitive tutor.
- Each domain requires a dedicated and idiosyncratic task analysis.
- Any instruction based upon cognitive models will require a task analysis.
- Instructional effectiveness "is a function of the task analysis" (2000, p. 22) upon which it was designed.

The purpose of the task analysis is to align instruction with targeted knowledge. Task analysis is actually long-standing procedure inherent within the process of design as implemented within the instructional technology field (e.g., Clark, Feldon, Merriënboer, Yates, & Early, 2008; Gagné, 1962, 1965, 2012/2000/1968). If task analysis determines instructional effectiveness, it should be a requisite component of all cyberlearning environment design. In addition to cognitive tutors, the nation's cyberlearning agenda includes simulations, videogames, and virtual worlds. The Quellmalz, Timms, and Schneider (National Research Council [NRC], 2011; Quellmalz, Timms, & Schneider, 2009) review of the literature discovered that, in general, instructional games and simulations lack rigorous alignment with to-be-learned knowledge. Their literature review did not directly address instructional virtual world design, but the overlap among these three categories suggests virtual world design might also lack rigorous alignment.

Anderson and Schunn (2000) lamented a general lack of scholarly support across domains and fields for rigorous task analyses. A concerted effort could produce a repository containing cognitive models for the formalized domains, those domains served by the academic study designed to prepare individuals for literacy and professional endeavor. Such cognitive models would support a coherent, robust, and accurate migration from formalized knowledge to cognitive tutors, simulations, virtual worlds, and instructional games. The Project 2061 *Atlas of Science Literacy* (American Association for the Advancement of Science [AAAS], 2001, 2007) aims to enhance instruction that leads to scientific literacy for all by identifying core scientific ideas and concepts and organizing them into developmental strand maps categorized by grade ranges and interconnected topics. Efforts such as the *Framework for K-12 Science Education* (Committee on Conceptual Framework for the New K-12 Science Education Standards & National Research Council, 2011) and the *Next Generation Science Standards* suggest mindsets and climate that might support the substantial investment required to define cognitive models for core disciplinary ideas.

2.2 Alignment Requirements for Cyberlearning Assessments

A primary overarching principle within the field of instructional design is alignment among targeted knowledge, instruction, and assessment tasks (e.g., Gagné, Briggs, & Wager, 1992; Smith & Ragan, 1993, 2005). As R. F. Mager put it (1984, as cited in Smith & Ragan, 1993, 2005):

- Goals and objectives: Where is the learner going?
- Instruction: How does the learner get there?
- Assessment: How do you know the learner's arrived?

Working from diverse perspectives, other fields and organizations have developed complementary models.

The National Research Council (NRC) Committee on the Foundations of Assessment followed the thrust of NRC's volume(s) on *How People Learn* (Bransford, Brown, & Cocking, 2000) with a focus on assessment. The assessment committee conducted and reported a 3-year effort to study assessment from the perspectives of cognitive and measurement sciences. Their report, *Knowing What People Know: The Science and Design of Educational Assessment* (National Research Council Committee on the Foundations of Assessment, Board on Testing and Assessment, & Division of Behavioral and Social Sciences and Education [NRC et al.], 2001), proposed an assessment triangle. The three legs are:

- Cognition. "A model of student cognition and learning in the domain" (p. 44).
- Observation. "Description or set of specifications for assessment tasks that will elicit illuminating responses from students" (p. 47). Assessment tasks derive from developers' beliefs about "the kinds of observations that will provide evidence of students' competencies" (p. 48).
- Interpretation. "An interpretation process for making sense of the evidence" (p. 48).

The triangle is a foundation for aligning interdependent relationships among the to-be-learned knowledge, assessment tasks, and interpretation of those data as measures of learning: "…to have an effective assessment, all three vertices of the triangle must work together in synchrony" (p. 51), and multiple iterations may be required to adjust and optimize that alignment.

Baker, Chung, and Delacruz (2007) reviewed computer-based scoring approaches used within technology-based performance assessments. They identified "domain modeling" as scoring methods based upon a priori mapping between a to-be-learned (or demonstrated) knowledge specification and the performance-based assessment task variables. They too find "the most important issue in domain modeling is identifying the essential concepts and their interrelationships. This challenge is mitigated via thorough knowledge acquisition activities such as cognitive task analyses and direct observation of performance" (p. 601).

NRC assessment committee member Robert Mislevy continues to refine, elaborate, and develop the framework he had contributed to the 2001 report. His evidence-centered design (ECD, e.g., Mislevy, Steinberg, & Almond, 2003) provides a framework for "linking goals and assessment within situated contexts" (Klopfer, Osterweil, & Salen, 2009, p. 37) like simulations. Mislevy (2011) counseled that

> …The move from simulation to simulation-based assessment is not simple. For instance, the principles and tools needed to create valid assessment in simulation environments are not the same as those required to build simulations (or even to use them for learning) (Melnick, 1996). One challenge is that the development of a valid simulation-based assessment requires that expertise from disparate domains come together to serve the assessment's purpose (typically including subject matter knowledge, software design, psychometrics, assessment design, and pedagogical knowledge). Few people are experts in all of these domains; fortunately, it is sufficient to have a shared design framework [ECD] in which each team member can see how his expertise fits in with others. (p. 2)

Mislevy's ECD framework conceptualizes the process of assessment design, development, and implementation as interdependent layers. In a 2011 report for the National Center for Research on Evaluation, Standards, and Student Testing, Mislevy described the application of ECD to assessment within simulations. The first three layers (Mislevy, 2011, p. 7) dovetail with knowledge specification and its mapping to a game world:

- Domain analysis: The ECD analysis asks, "What is important about the domain? What work and situations are central in the domain? What knowledge representations are central?"

  Mislevy identifies task analysis and cognitive task analysis as ECD knowledge specification techniques. CyGaMEs is an instructional design approach and conducts knowledge specification through study of the literature and, especially, interviews and studies of domain experts to elicit their expert model for a targeted concept. In the case of *Selene*, the targeted concepts are fundamental principles underlying planetary geology (which subsumes Earth science).

- Domain modeling (conceptualization): How can an assessment argument represent key aspects of the domain?

  In the CyGaMEs approach, the to-be-learned domain is the target domain of an analogy between the abstraction or scientific phenomenon and a concrete game world.

- Conceptual assessment framework (generativity): Design student, evidence, and task models.

  In CyGaMEs the concrete game world represents the targeted domain model as embodied transactions. Game scaffolds guide and constrain learners to achieve the game goal(s) (analog of a targeted learning goal[s] through the [virtual] physical transactions of gameplay).

3 The CyGaMEs Approach to Designing Instructional Games with Embedded Assessment: *Selene*

3.1 Theoretical Foundation

The CyGaMEs approach to instructional game design with embedded assessment is applied analogical reasoning theory. The method assumes people form their base conceptual knowledge from embodied transactions with the environment (Lakoff, 1987; Lakoff & Johnson, 1980, 1999), a form of problem solving (Jonassen, 2006). Then these basic-level conceptualizations serve as a base domain for inferences about unfamiliar or more abstract target domains, and so on.

For example, the toddler who blisters her fingers on the door of the oven cooking the Thanksgiving turkey is told not to touch because "the oven is hot." In the spring she obeys her brother when he warns "Hot!" at the family backyard bonfire and sits back down instead of reaching for a burning stick: an analogical inference from concrete to concrete. Later, she cries "Hot!" through her tears after a taste of spicy chili: a more abstract inference from base to target. As a tween watching a music performer, she remarks he is "really hot." The analogy connects physical reactions to arousal to more abstracted emotional or cognitive responses. At school during the unit on electricity, she learns that currents running through old-fashioned, incandescent lightbulbs make them hot, a form of radiant energy. The atoms that make up the thin wire in the lightbulb resist the free electrons in the current. The electrons in the current bump into the atoms in the wire. This heats up the atoms and wire. And she begins to wonder. Using the lightbulb as the base, she thinks back to the oven. She thinks the oven might be like the lightbulb, with current making the element hot. She uses the oven as the base and infers that a fire burning wood might be like the electric oven. When you turn on the stove or oven, electrical energy makes the elements red and hot. When you burn sticks in a campfire, there might be a similar process that produces radiant energy, which makes the fire red and hot. The campfire is certainly not electricity, but it might be something like it. She has made a series of plausible inferences by mapping from one domain to another. Plausible inferences are fallible, especially when proposed by a domain novice. In this case the process of electric heating because of resistance in a wire is quite different heat from the chemical reaction that produces a fire. One purpose of instruction is to enhance the educational quality of day-to-day lived experience. Instruction should provide lived experience that engenders viable analogical inferences for targeted knowledge and pedagogical content knowledge (e.g., pedagogical metaphors, Petrie & Oshlag, 1993; and pedagogical content knowledge, Shulman, 1987).

Structure mapping theory explains that learning and higher-order reasoning are best served when people map viable relational structure from a base domain to a target domain.

3.1.1 Structure Mapping Theory

A domain can be conceptualized as composed of objects, their attributes, and the relations between objects (Gentner, 1983). In the 1970s cognitive scientists began to study cognition using specifications of domains (Holyoak, 2012). Within these knowledge representations, objects functioned in roles based upon their location within the relational structure of the domain. An attribute modified or described an object. A relation connected two objects. Although people typically are unaware they are engaged in this cognitive process, people make analogies by placing two domains in alignment (Gentner, 1983; Gentner & Markman, 1997). They map relational structure from a base domain to a target domain. The structure in the two domains is inferred to be parallel, but the objects in the base domain are replaced by objects in the target domain. According to structure mapping, the greater the degree of parallel structure, the stronger the analogy.

Domain novices typically exhibit limited ability to identify relevant information, to integrate information, or to enact relevant procedures (Mislevy, 2011; Salthouse, 1991). This is why children and other domain novices often construct analogies according to superficial characteristics. For example, they might map an analogy according to color (e.g., a lollipop is red and a burner on a stove is red, Gentner & Markman, 1997). Inferences from a lollipop to a stove would be unfortunate but quickly corrected. Inferences produced through embodied experience, like the mapping from the kitchen stove to the campfire, may be more deep seated and intractable. Superficial analogies often lead to entrenched alternative conceptions or misconceptions that impede learning. Naïve conceptions about scientific phenomena are usually incoherently structured, robust, and intransient (e.g., Chi & Roscoe, 2002; Hestenes, Wells, & Swackhamer, 1992). Domain experts know what is relevant to a domain, how to discriminate components, and how components interrelate (Salthouse, 1991). This enables them to form plausible analogies according to deep relational structure. In general, the deeper or more systematic the shared relational structure, the more likely an analogical mapping from the known to the unknown will support viable inferences. This *systematicity* principle (Gentner, 1983) is widely supported by research and the field (e.g., Holyoak, 2012; Holyoak, Gentner, & Kokinov, 2001). Learning and higher-order reasoning are best served when two domains share deep systematicity rather than superficial mapping according to attributes.

Although Gentner (1980) uses prepositional networks for knowledge representation, she advised other representational systems might serve equally well. The CyGaMEs approach currently uses concept maps (Novak & Gowin, 1984; Novak & Musonda, 1991) for knowledge representation. Concept maps represent objects (subconcepts) as labeled ovals and the relations between objects as directional arcs.

3.1.2 Pragmatic Constraints

While analogical reasoning favors structural comparisons in which the elements of both base and target domain share the same pattern of relational roles, mapping and inference making are also directed and constrained by the analogizer's immediate goals and the context of the analogy (Holyoak, 2012; Holyoak & Thagard, 1989). Role-based reasoning might be a more descriptive label for the cognitive process of analogical reasoning. People engage in analogical reasoning by mapping from base to target based upon the relational roles played by objects (e.g., subconcepts). For example, in the predicate "A attracts B," both A and B are objects acting in the role determined by the relation "attracts." The analogizer's immediate goals may determine the individual's approach to mapping correspondences, or the goals may override correspondences. Together, pragmatic constraints and structure mapping explain how humans engage in role-based reasoning. When a more familiar domain (base) and less familiar domain (target) seem to share relational structure, the analogizer makes inferences that map objects from the target to slots in the relational structure of the base.

It is often difficult for a novice, like the tween in the fire example, to identify which aspects of a domain are salient to targeted learning. That's where instruction comes in. An instructional design team can identify the relational structure of the target domain and design a source domain to highlight the salient components of that relational structure.

3.1.3 Instructional Game Worlds as Analogs of Targeted Knowledge

Introductory learning in science domains is often challenging because the natural phenomena occur on scales that are too large, small, quick, or slow for embodied human transactions. Or concepts may be defined abstractions. Novice learners often have little or no viable prior knowledge for these domains (Hestenes et al., 1992; Johnstone, 1991). The affordances of game-based technologies provide a way to apply analogical reasoning and design embodied experiences that assist learners to construct viable prior knowledge. Game worlds have *objects* that afford *transactions* for a player who *manipulates* them according to *rules* to attain game *goals*. Game worlds can be analogs of targeted knowledge to guide, scaffold, and reward the player to discover and apply concrete, embodied analogs for targeted knowledge. This requires task analysis to specify the relational structure of targeted knowledge and learning goals. Then, structure mapping and pragmatic constraint theories are applied to the process of game design and development (Reese, 2009).

Although Mislevy's ECD method does not apply analogical reasoning theory and does not seek to develop simulations as analogs, Mislevy makes similar and applicable recommendations about simulations designed for learning and assessment that apply to instructional game design (2011, p. 4):

- Simulation environments should "highlight the key features of relevant situations."
- "Higher fidelity to real world situations does not necessarily make for better learning or better assessment."
- "Fidelity with respect to targeted knowledge or skill (at the targeted level) is more important."
- Focus "on the features of situations that provoke the targeted knowledge and skills" at a level appropriate to the expertise of the learner.

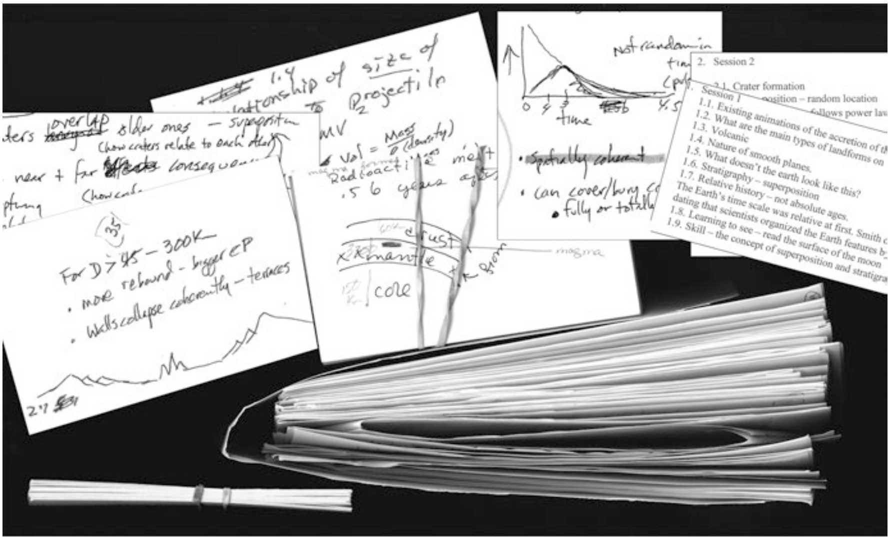

Fig. 16.1 Sample of artifacts from the CyGaMEs *Selene* task analysis sessions with the lunar science expert. Copyright 2012 Debbie Denise Reese. Used with permission

3.2 Domain Specification for CyGaMEs Selene

The CyGaMEs metaphor specialist began the *Selene* task analysis on Nov. 6, 2006, and presented the first iteration of the 101-node concept map to the subject matter expert for consultation review during a 2-h session on Dec. 20, 2006. Lunar scientist subject matter expert Dr. Charles A. Wood is one of the lunar geologists who discovered the science modeled in *Selene*. His papers are archived as classics in the field (Cruikshank, Hartmann, & Wood, 1973; Cruikshank & Wood, 1972; Hartmann & Wood, 1971; Wood, 1972, 1973), and this, the science within *Selene*, is accepted as conceptually foundational within the corpus today. Wood continues this work studying and popularizing the stratigraphy and originals of the Earth's Moon (Shirao & Wood, 2011; Wood, 2003) and those of Saturn (e.g., Lorenz et al., 2011; Wood et al., 2010). He is also a CyGaMEs coprincipal investigator. Thus, we used just Wood as our expert. Eighteen 1-h sessions with Wood, augmented by external readings of other sources and his book, *The Modern Moon: A Personal View* (2003), produced a set of iteratively refined raw session notes and diagrams (see Fig. 16.1). As the sessions progressed, the metaphorist synthesized the content into note cards for annotations and then began the process of representing the relational structure of the subconcepts within one integrated concept map. On Dec. 20 the metaphorist, Wood, and an external expert met for review of the concept map draft.

The artifacts in Fig. 16.1 include session raw diagrams and notes, typed notes, and index cards annotating identified concepts. Each session began with a review of processed notes from the previous session and produced its own set of notes.

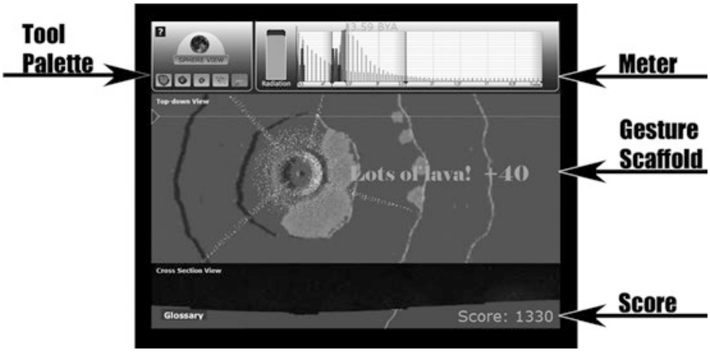

Fig. 16.2 Graph from task analysis notes as represented within the *Selene* Surface Features module. Copyright 2012 Debbie Denise Reese. Used with permission

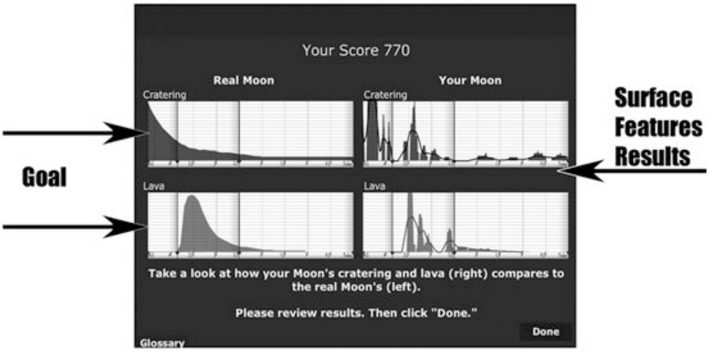

Fig. 16.3 Graph from task analysis notes used in *Selene* Surface Features results feedback module of game goals (left) and player performance (right). Copyright 2012 Debbie Denise Reese. Used with permission

The diagram of the layers of the differentiated Moon (Fig. 16.1, center under rubber band) developed into the *Selene* game Differentiation module, one of the Accretion module goals, and the Accretion module results feedback screen. The graph of the amount of lava and impact cratering activity over the Moon's 4.5 billion year history (Fig. 16.1, left top graph) became the *Selene* Surface Features module goal states, player feedback graph, and Surface Features results feedback to the player (see Figs. 16.2 and 16.3). The diagrams of crater topography and morphology (e.g., Fig. 16.1, left) were represented in the game as basins and central peaks.

3.3 The Concept Map

The *Selene* concept map contains 101 subconcepts. Projection on a computer screen with capacity to magnify views or a 4-foot wide print is required to read the labels

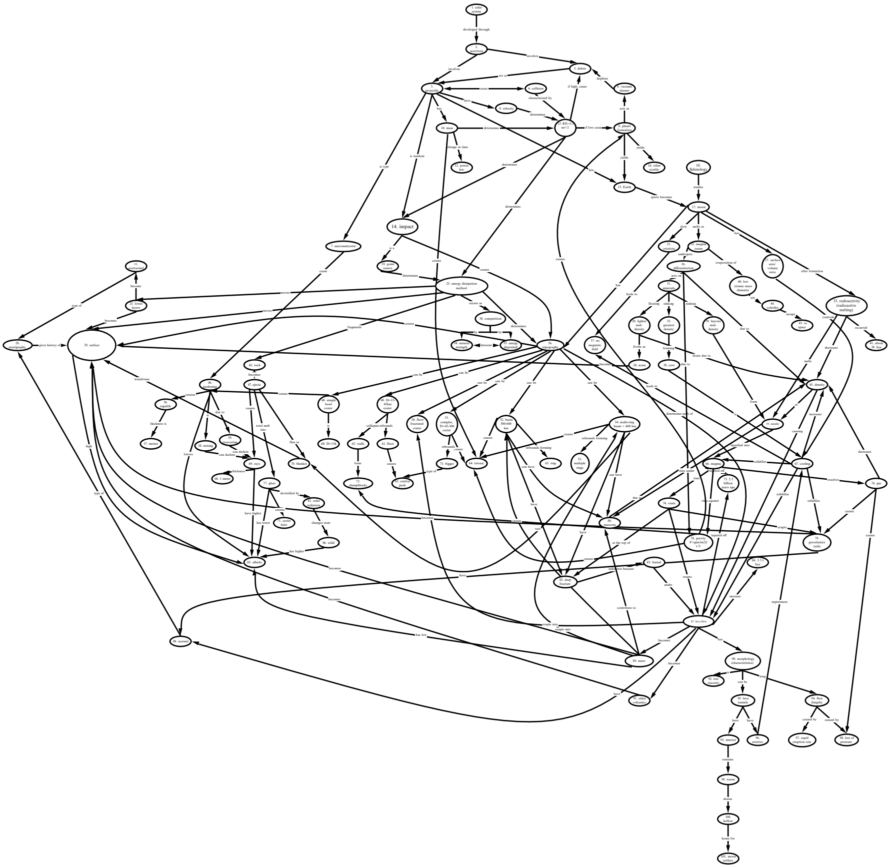

Fig. 16.4 The *Selene* concept map: 101 subconcepts. Copyright 2007 Debbie Denise Reese and Charles A. Wood. Used with permission

of subconcepts and relations, but Fig. 16.4 illustrates the structure of this knowledge representation (labels can be read at high magnifications of the chapter PDF file). Tables 16.1 and 16.2 list the 101 subconcepts. The process for representing the domain as a concept map followed the procedures developed by Joseph Novak and his colleagues (Novak, 1990; Novak & Gowin, 1984; Novak, Gowin, & Johansen, 1983; Novak & Musonda, 1991). Subconcepts are labeled and represented by ovals and relations between them by directional arcs. Details of the CyGaMEs mapping method and its application of concept maps within this domain and others are available elsewhere (Diehl & Reese, 2010; Reese, 2003a, 2003b, 2008, 2009; Reese & Coffield, 2005). Each target concept is numbered, and the numbering is used for documenting alignment between the knowledge specification and the learning environment. The *Selene* game was developed to align with the map in Fig. 16.4. CyGaMEs provided developers a blank concept map for use in mapping game objects and relations to the specification. *Selene* developers were permitted to skip

Table 16.1 The 76 concepts from domain specification concept map explicitly incorporated into *Selene*. Copyright 2012 Debbie Denise Reese. Used with permission

1. Solar system	44. Volatiles
2. Accretion	45. Density
3. Projectile	46. Gardening
4. Collision	47. Ejecta
5. Debris	48. Simple bowl crater
6. Vacuum cleaner	49. Crater diameter = 15–45 km
7. Micrometeorite	51. Complex crater 45–300 km
8. Planet formation	53. Multiple rings
9. Velocity	54. Multi-ring basin > 600 km
10. Mass	55. Mantle
11. Overturned	58. Mixing
12. Power law	59. Excavating
13. $KE = \frac{1}{2}MV^2$	60. Crater diameter < 15 km
14. Impact	61. Floor
15. Earth	62. Walls
16. Other worlds	63. Central peak
17. Moon	64. Terrace
18. Selenology	65. Ring
19. Point source	66. Magma
20. Lighter mid-density	67. Cooling
21. Rotation	68. Thickness 1 m
22. Magma ocean	69. Rays
23. Lower layers	70. Blanket
25. Energy dissipation method	73. Bigger
26. Differentiation	74. Vents
27. Surface area/volume ratio	75. Tapered off 2.5 BYA
28. Stratigraphy	78. Gravity: $F = g(m1 \cdot m2)/r^2$
29. Surface	81. Solar radiation
31. Minerals	82. Deep fracture
32. Greatest density	83. Buried
33. Radioactivity (radioactive melting)	84. Increase 3.7–1 BYA
36. Topography	85. Albedo
38. Core	87. Lava flow
39. Heavier mid-density	88. Normal
40. Low atomic mass elements	89. Mare
41. About 0.56 BYA	90. Morphology
42. Rock	92. Low viscosity
43. To space	

individual concepts or sections of the map as long as the integrity of the map was retained. That is, the omitted concepts could be or could have been added to the environment without violating any mapped relation. Tables 16.1 and 16.2 categorize subconcepts by inclusion or exclusion within the Selene game.

A crosswalk table, produced to guide, ensure, and document alignment between each concept, also supports the case for validity. Table 16.3 contains an excerpt from the *Selene* crosswalk table.

Table 16.2 The 25 concepts from domain specification concept map not incorporated or not explicitly incorporated into *Selene*. Copyright 2012 Debbie Denise Reese. Used with permission

24. Scum	71. Crater halo	94. Flow (length)
30. Competition	72. Slump blocks	95. Interior
34. Natural strength	76. Gas	96. Exterior
35. Energy deposited	77. Glass	97. Rapid eruption rate
37. No magnetic field	79. Pyroclastics (ash)	98. Lots of pressure
50. Floor fractured crater	80. Mascons	99. Warm
52. Basin 300–600 km	86. Solid	100. Hollow
56. Regolith	91. Other volcanics	101. Moon settlers
57. Meters	93. Lava tunnels	

Table 16.3 Excerpt from CyGaMEs *Selene* crosswalk table: alignment exercise

Concept from map	Concrete game analog
1. Solar system	Solar system in the Accretion cinematic
2. Accretion	Debris sticking together in the Accretion animation
2. Accretion	Gravity in Accretion gameplay
2. Accretion	Anytime mass is added, and persist, to the protoMoon
3. Projectile	Particles in solar system Accretion
3. Projectile	Particles in Differentiation cinematic
3. Projectile	Projectiles in Accretion gameplay
3. Projectile	Projectiles in Surface Features gameplay
4. Collision	The collisions in the Accretion animation
4. Collision	The collisions of projectiles with the protoMoon in Accretion
4. Collision	Projectiles collisions with surface of the Moon in Surface Features
5. Debris	The Accretion animation
5. Debris	Non-clicked on projectiles in Accretion gameplay
5. Debris	Debris from high-velocity impacts in Accretion gameplay
6. Vacuum cleaner	Planet formation portion of the Accretion animation
7. Micrometeorite	Surface Features gardening tool (the icon for the gardening tool)
8. Planet formation	Planet formation in Accretion animation
8. Planet formation	Moon growing and resulting from the accretion in Accretion gameplay
9. Velocity	Length and direction of the shooting line in Accretion
9. Velocity	Length and direction of the shooting line in Surface Features
10. Mass	Masses of projectiles in Accretion
10. Mass	Different projectiles in Surface Features
11. Overturned	The effect of the impact cratering in Surface Features
12. Power law	The graph encouraging people to shoot less projectiles at the Moon as time passes
12. Power law	The game goal for impact cratering in Surface Features
12. Power law	Sphere view has less debris orbiting it over time
13. $KE = ½ MV^2$	Modeling of heat and movement through the physics engine in Accretion gameplay
13. $KE = ½ MV^2$	Formula used to determine radius of a crater in Surface Features
14. Impact	Collisions between the surface of the Moon and the different projectiles in Surface Features

Completed 04-06-2010 (excerpt from Five-Page Crosswalk Table). Copyright 2012 Debbie Denise Reese. Used with permission

CyGaMEs specification is a bit recursive, with the concrete representation producing insights that require modification to the original specification. Collaboration with game designers and developers has provided insights that fed back into the knowledge representation, leading to minor map modifications. *Selene* has progressed through two development cycles: *Selene Classic* with lead Ian Bogost at Georgia Tech (Accretion and Differentiation modules, Will Hankinson; Surface Features module, Matt Gilbert. Hankinson and Gilbert were graduate students at the time) and *Selene II* with Second Avenue Software (now Second Avenue Learning).

3.4 Timed Report: Learning Analytics Through an Embedded Measure of Game-Based Learning

Interpretation of game-based data for assessment is one of the "frontiers in contemporary psychometrics" (Mislevy, 2011, p. 16; see example of psychometric treatment of gameplay data as framed by ECD at Rupp, Gushta, Mislevy, & Shaffer, 2010). Lack of alignment between instructional games, assessment instruments, and targeted knowledge is documented (NRC, 2011; Quellmalz et al., 2009) and limits the validity and effectiveness of current instructional game embedded assessment and research on game-based learning. Typically, new paradigms of assessment approach such data through item response theory, Bayes nets, and hidden Markov models (Timms et al., 2012). In many cases data from virtual worlds and learning games are player responses to multiple-choice items, and decisions are used as gameplay to interface with the game world and advance play toward the game goal. Frequently, a post hoc approach mines data to attempt to discover relationships or patterns that might represent learning. Mislevy recommends a priori approaches that develop measures based upon targeted learning and identify measures before data collection (Mislevy, 2011). Even so, the longitudinal nature of this and other gameplay data presents challenges for traditional psychometric approaches (Mislevy, 2011; Rupp et al., 2010).

The CyGaMEs process designs for alignment between the game and the targeted domain knowledge by specifying the targeted knowledge as a concept map and designing the game as an analog of that map. Because game goals are analogs of targeted learning goals, a CyGaMEs environment measures knowledge growth as player achievement: player progress toward the goal. These CyGaMEs Timed Reports are built into the game based upon game goals and gameplay. Data are not responses to multiple-choice items. Rather, as I will illustrate in Sect. 3.5, a Timed Report is a quantified snapshot of gameplay behavior. Gameplay behavior is a procedural activity that embodies cognitive decisions discovering, manipulating, and applying targeted content. CyGaMEs measures are embedded assessment and are not like scales, which have measurement error. CyGaMEs measures are part of the activity and cannot be divorced from it. CyGaMEs measures show what the player did. They reflect the activity directly, mechanically, and automatically; inherently, they are reliable. In case of failure of automation (data fail to arrive through the Internet), the data would reflect noncompletion, and the player would be removed from our sample. CyGaMEs datalog algorithms detect and tag suspicious data.[3]

The longitudinal nature and volume of reports within CyGaMEs data are not problematic. Timed Report data have been analyzed and interpreted using traditional statistical methods such as repeated and multivariate ANOVA and hierarchical linear modeling (Reese et al., 2012; Reese & Tabachnick, 2010).

We have identified two types of learning goals:

- Static. A game segment has one or more static goals. The player discovers and applies targeted knowledge throughout the segment to reach those goals. When all goals for a segment are reached, the player progresses to the next segment, goal(s), and challenge(s). The *Selene* Accretion module contains three sections. Each section comprises one or more static goals.
- Dynamic. A game segment models a natural process as a dynamic change over time. Each of the three segments of the *Selene* Surface Features module models two dynamic goals. Goal states change and update every gameplay second (see Fig. 16.2 [Meter] and Fig. 16.3).

The CyGaMEs Timed Report collects quantitative measures of player progress toward each game goal every 10 s of gameplay. We selected 10 s because it is a time at which

> …knowledge is available from the environment about what to learn, namely experience attained in working at ~~ 10 sec… The occasions for learning new information show up in the ~10 second range. It is governed by the opportunity for acquisition. It locates its cause in conditions for learning. (Newell, 1990, p. 149)

Given the time required to initiate and complete *Selene* gameplay gestures and drain on computer resources, 10 s also gives a meaningful snapshot of player activity.

3.5 The Surface Features Example: Player Learning Trajectories

A case example of *Selene* gameplay data with comparison to game goals illustrates veridicality and interpretation of Timed Report assessment as one approach to learning analytics.

The *Selene* Surface Features module (see Fig. 16.2) was designed according to the concept map (see Fig. 16.4). During the process developers required additional guidance. In addition to weekly content meetings, we augmented the ontology by specifying investigation questions, key understandings, and underlying science.

[3] The author thanks research partner Barbara G. Tabachnick for contributing this paragraph.

3.5.1 Elaboration of Ontology

Investigation questions

- What controls the size and shape (morphology) of impact craters?
- What determines the scenery (stratigraphy) of the lunar surface?
- What are the dark splotches on the Moon?
- Why, how, when, and where did volcanism occur?

Key understandings

- Craters: The amount of kinetic energy of the impact controls the size and shape (morphology) of impact craters.
- Craters: The strength of the target rocks modulates morphology.
- Surface: Impact craters redistribute subsurface material across the surface.
- Surface: Lava flows and cratering intermingle.
- Surface: Fragmented materials darken with time.
- Lava—why: Radioactive heating occurs in the upper mantle.
- Lava—why: Lunar volcanism is caused by radioactive heating in the upper mantle (and not differentiation).
- Lava—why/how/where: Magma is less dense than surrounding rocks and buoyantly rises toward the surface, preferentially along basin fractures.
- Lava—why: Two kinds of volcanism: explosive (small %—not covered in *Selene*) and effusive (flowing).

Underlying science

- Stratigraphy is the record of time sequence of events.
- Kinetic energy is dissipated by modifying rocks in various ways.
- Kinetic energy is expended in breaking, melting, and moving rocks.

3.5.2 Game Goals

Informed by the investigation questions, key understandings, and underlying science, game designers mapped the ontology impact cratering and volcanism components as the *Selene* Surface Features module. Surface Features models natural phenomena that decreased over 4.5 billion years. *Selene impact cratering* (y_{IC}) can be approximated by a function that follows an exponential decline (where $x = 10$ gameplay seconds and $R^2 = 0.97$)

$$y_{IC} = 90.07e^{-0.087x} \tag{16.1}$$

Selene lava flow (y_{LF}) approximates with the polynomial (where $x = 10$ gameplay seconds and $R^2 = 0.99$)

$$y_{LF} = -0.0002x^6 + 0.017x^5 - 0.483x^4 + 7.060x^3 - 52.89x^2 + 175.53x - 111.96 \tag{16.2}$$

Each player replicates 4.5 billion years of geologic history, following dynamic goal states for impact cratering and volcanism that update every gameplay second (see Fig. 16.2, meter, and Fig. 16.3, goal).

3.5.3 Calculating *Selene* Surface Features Timed Report

Figures 16.2 and 16.3 display the data used by the *Selene* game and processing algorithms for Surface Features Timed Report. The height of the vertical lines in the Fig. 16.2 meter and the height of the shading in the two graphs to the left in Fig. 16.3 plot the goal states. The shading in the Fig. 16.2 meter and the two graphs to the right in Fig. 16.3 plots a player's gameplay for each dimension (impact cratering and lava flow). Goals activate and gameplay updates every game second. Every gameplay 10 s, the Timed Report algorithm calculates and posts the average height over that interval of:

- The player's impact cratering
- The player's lava flow
- The game goal impact cratering
- The game goal lava flow

Then progress is calculated as

$$y = 1 - |T - C| \tag{16.3}$$

where T = Target (goal) and C = Current player achievement.

If there has been no dimension gameplay within an interval for which that dimension's goal state was greater than zero, the player progress = 0. Using this and (16.3), each Timed Report score ranges between 0 (low) and 100 (high).

3.5.4 Surface Features Case Study: Player 2585

Player 2585 is a 14-year-old girl. Figures 16.5 and 16.6 illustrate her learning trajectories as progress toward the game goal during two rounds of gameplay. Figure 16.5 illustrates the raw data of her progress, as plotted on the Surface Features gameplay meter (see Fig. 16.2) and Surfaces Features results module feedback (see Fig. 16.3). The *X* axis displays gameplay time in units of 1-s game time. For ease of interpretation, time on the Fig. 16.5 *X* axis is labeled in gameplay round and time periods. For example, "1~1" represents round 1, time period 1. Each round of Surface Features gameplay models 4.5 billion years ago to the present. A comparison of player achievement to goal states suggests this player has an established mental model of lunar cratering and lava phenomena over time.

Figure 16.6 plots her 10-s Timed Report data after application of (16.3). Once again, time on the *X* axis is labeled in gameplay round and time periods. Table 16.4 provides the number of Timed Reports for each segment of gameplay for each of the gameplay goals. For example, the number of Timed Reports per second for this

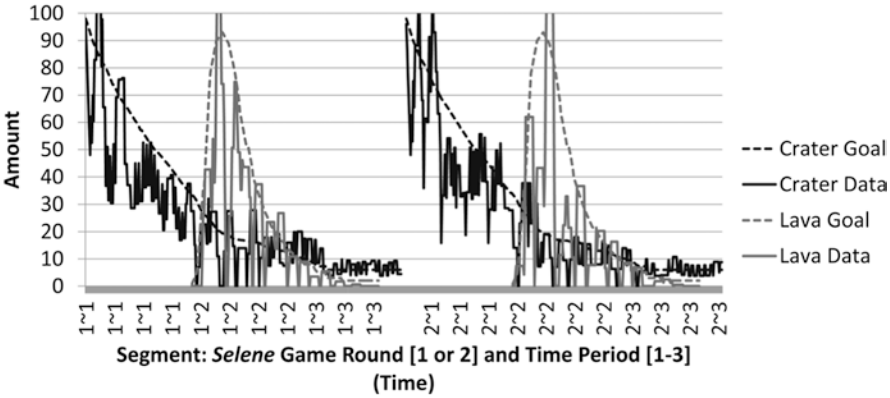

Fig. 16.5 Player 2585 progress toward each Surface Features game goal, reported each gameplay second over two rounds of gameplay. Copyright 2012 Debbie Denise Reese. Used with permission

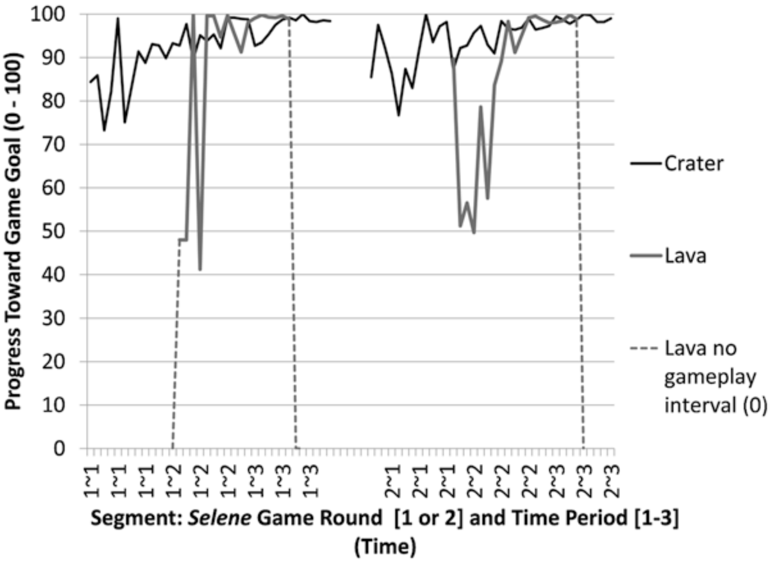

Fig. 16.6 Player 2585 Surface Features Timed Report learning trajectory by segment (time). Copyright 2012 Debbie Denise Reese. Used with permission. *Note*: Lava no gameplay intervals scored as 0 (no progress): Round 1 first interval ($n = 1$) and final intervals ($n = 2$); Round 2 final interval ($n = 1$)

player was typically 12. Exceptions are due to the characteristics of the natural phenomena modeled by the game. Timed Reports for lava are not collected during time period 1 because the Earth's Moon did not experience lava activity this time. Lava activity during time period 3 ends before the end of actual gameplay because lava activity ceased on the Moon during this period. In both round 1 and round 2, the number of reports for this player during time period 3 = 8.

Table 16.4 Descriptives for player 2585 Surface Features Timed Reports over two rounds of gameplay (six segments) for goals impact cratering and lava

Segment		Descriptives						
Round	Time period	Dimension	*N*	Min. (%)	Max. (%)	Mean (%)	SE	SD
1	1	Crater	12	73.2	99	86.6	2.2	7.5
		Lava	–	–	–	–	–	–
	2	Crater	12	89.6	99.2	95.5	0.9	3.2
		Lava	12	0.0	99.9	76.3	9.6	33.4
	3	Crater	12	92.7	100	97.4	0.7	2.3
		Lava	8	0.0	99.8	74.5	16.3	46.0
2	1	Crater	12	76.7	100	90.8	2.1	7.1
		Lava	–	–	–	–	–	–
	2	Crater	12	87.4	99.0	94.7	1.0	3.5
		Lava	12	49.7	99.2	78.3	5.5	19.1
	3	Crater	12	96.5	99.9	98.4	0.3	1.1
		Lava	8	0.0	99.8	86.4	12.4	34.9
Overall	–	Crater	72	73.2	100	93.9	0.7	6.1
	–	Lava	40	0.0	99.9	78.6	5.1	32.0
	–	Lava excerpt[a]	36	41.2	99.9	87.3	3.2	19.2

Scores may range from 0 to 100 %.
[a]Descriptives for lava Timed Reports with scores for intervals of no gameplay scored as (0), no progress, removed. Reports deleted from average: round 1 first interval ($n=1$) and final intervals ($n=2$); round 2 final interval ($n=1$)

Table 16.5 Timed Report lava trials within which player 2585 did not engage in gameplay

	% lava achievement	
Trial within round	Round 1	Round 2
1	No gameplay	90
19	No gameplay	99
20	No gameplay	No gameplay

The amount of activity for both lunar impact cratering and lava flow decreased to at or near zero as time approached the present day. Using the algorithm, a player with no gameplay would appear to progress closer to the game goals. For this reason we score 10-s intervals of *no gameplay* as zero progress (0 %) in place of (16.1). The zero progress correction provides a conservative estimate of learning. Player 2585 completed three round 1 Timed Report intervals (first and final intervals) and one round 2 interval (final interval) with no lava gameplay (see Table 16.5). The Moon's period of volcanic activity seems to have occurred approximately 3.85 billion years ago to 1.1 billion years ago (see Figs. 16.2 and 16.3). This is the model for *Selene* volcanism. *Selene* penalizes players for placing lava vents before or after active volcanism. Player 2585 engaged in lava gameplay for all intervals except the four initial-terminating intervals noted. Players may have difficulty estimating the exact stopping point for lava activity (see Fig. 16.2, meter, and Fig. 16.3, goal). It is possible player 2585 misestimated the exact starting and ending points for lava activity. Her interpretation of the goal meter start and ending points seems to have improved over time since her round 2 gameplay corrected the missing trial 1 and trial 19 intervals missed in round 2. A less conservative interpretation based upon her gameplay achievement deletes the leading and training zero intervals. Table 16.4 reports overall mean lava achievement with and without intervals of no gameplay. Mean impact cratering achievement by round and time period for player 2585 ranges from 86.6 to 98.4 % (M=93.9). Mean lava achievement ranges from 78.3 to 86.4 %, with an overall mean of 78.6 %. With the initial and final intervals (the no lava gameplay intervals; see Table 16.5) removed from the calculation, player 2585's lava achievement, M=87.3, is similar to that of the impact cratering dimension.

Data collected from 267 players (M_{age}=15) shows a median cratering achievement of 75 % and median lava performance of 59 % across the two rounds and three time periods of gameplay. Individual achievement for player 2585 and comparison to her peers suggest player 2585 is a high-achieving *Selene* player. During a one-on-one interview, player 2585 accurately described and interpreted her assessment reports (see Fig. 16.4), the game components, and the targeted scientific phenomena. Together, gameplay and interview provide convergent evidence that player 2585 had mastered the content and that the game assessment is sensitive and accurate.

4 Discussion

4.1 Games as Interactive Digital Knowledge Maps that Teach and Assess

The CyGaMEs formalism, the *Selene* game, the Timed Report embedded assessment instrument, and an illustrative case of gameplay behavior as assessed by the Timed Report demonstrate how game-based environments can serve as digital knowledge maps that teach and assess. The Timed Report is the crux of the CyGaMEs approach to learning analytics. CyGaMEs is a formalism for producing learning environments that translate what is invisible inside experts' heads into virtually embodied transactions designed to prepare learners with the types of concrete experience that make learning more intuitive. Instructional games are powerful learning technologies that have the power to motivate, guide, reinforce, and measure learning. There may be many viable approaches to instructional game design and assessment. However, like analogical reasoning, the depth of learning within any instructional game is directly proportional to the degree of systematicity mapping the to-be-learned knowledge to the game world. The degree of ontological alignment by both game and the embedded assessment (the Timed Report or something like it that measures player progress toward the game goal analog for targeted knowledge) is an a priori determinant of the veridicality and appropriateness of data and the amount of information it can provide for learning analytics.

4.2 Expertise Required for Instructional Game Design

There are many ways to integrate instructional games into the events of instruction. Here, I concentrated on learning analytics when an instructional game is designed to cause and measure mental model formation and application as learners develop embodied prior knowledge. At the generative end (i.e., open-ended) of the spectrum, scholars and game producers develop environments that enable and empower learners to build their own games (e.g., Gamestar Mechanic: for project website see E-Line Media & Institute of Play (2013); for early publication describing the concept, see Salen, 2007). Whether game environments are closed- or open-ended (supplantive or generative), game design is a multifaceted and specialized skill, science, and art form (e.g., Fullerton, 2008; Fullerton, Swain, & Hoffman, 2004; Salen & Zimmerman, 2004; Schell, 2008). Instructional game design and development require rigor and multi-domain expertise (subject matter knowledge, software design, pedagogical knowledge, and *game design*). For example, ZeptoLab—designer/developer of the game *Cut the Rope*—claims that "ZeptoLab is an independent team of professionals dedicated to the science of fun. We know what good games are made of, and we possess the required ingredients" (ZeptoLab, 2012). The evidence supports their claims: (a) the public has downloaded *Cut the Rope* 60 million times and plays more than 6 million games each day, (b) 41,547 voters awarded an average of 4.7 stars out of 5 at play.google.com, and (c) critical appraisal of *Cut the Rope* gameplay mechanics and challenges garnered awards such as Best Handheld Game from the British Academy of Film and Television Arts (http://www.maclife.com/article/news/cut_rope_wins_bafta_award_best_handheld_game) and the 2012 Apple Worldwide Developers Conference (WWDC) Apple Design Award for best and most innovative software and hardware produced by independent developers (http://en.wikipedia.org/wiki/Apple_Design_Award#2012.5B3.5D). It seems that production of great instructional games will require more than expertise. Instructional game teams must include the type of exceptional talent that produces instructional games of a *Cut the Rope* caliber.

CyGaMEs is an approach for both instruction and assessment. In addition to team members who design and develop the game, CyGaMEs team expertise includes database design, learning analytics, assessment design, and general statistics. CyGaMEs recognizes that valid assessment requires psychometric expertise. Finally, the CyGaMEs approach requires an applied analogical reasoning specialist (the metaphorist or analogist role).

4.3 Toward Enhanced Capacity

Within this chapter I have attempted to introduce scholars, designers, leaders, policymakers, and educators to the rigor, expertise, and resources requisite for sound instructional game production. The process and resources required to produce a *Cut the Rope* or a *Selene* should provide evidence that a typical classroom teacher or academic is neither qualified nor sufficiently resourced to produce instructional games, especially games capable of learning analytics. The chapter described how knowledge maps can serve as the armature for process: instructional game design, its development, and embedded assessment through learning analytics. The chapter was designed to increase knowledgeable expectations, production, selection, and implementation of instructional games that produce learning analytics.

Initiatives like Project 2061 (AAAS, 2001, 2007), the *Framework* (Committee on Conceptual Framework for the New K-12 Science Education Standards & National Research Council, 2011), and the Next Generation Science Standards (NGSS, Next Generation Science Standards Team, 2012) represent pooled national expertise, collaboration, and investment to enhance lifelong achievement, human potential, and responsive and responsible global stewardship. These accomplishments are groundwork. In the sciences they identify developmental progressions, practices, crosscutting concepts, and core ideas that underlie academic, professional, and lifelong literacy and achievement. Agencies like the USA National Science Foundation (2012a, 2012b) and the Department of Education (U.S. Department of Education Office of Educational Technology, 2010) have established cyberlearning agenda that identify instructional games and embedded assessment as a national priority. Optimally, this will become a concerted global effort. Ontologies build on that groundwork. Ontology development is a requisite first step. But accurate and effective translation of targeted, essential knowledge into instructional games will require much more investment than does identifying frameworks and standards. Rigorous application of methods like a CyGaMEs approach requires adequate resources (e.g., human and financial capital) to follow ontology specification with game design development, testing, and research, integration and implementation, and learning analytics. Properly advanced, game-based technologies hold promise to transform education and increase human capacity across the life span.

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Part IV
Case Studies Investigating Digital Knowledge Maps

Chapter 17
Digital Knowledge Mapping as an Instructional Strategy to Enhance Knowledge Convergence: A Case Study

Darryl C. Draper and Robert F. Amason Jr.

Abstract This chapter discusses the effectiveness of digital knowledge mapping as an instructional strategy in an online graduate-level course at a North American university. Digital concept mapping tools would help students in constructivist online learning settings to collect ideas and generate and organize knowledge. The creation of digital knowledge maps enhances the cognitive processes, management, structuring, and restructuring of knowledge. Concept maps have proven to be a valuable cognitive tool in a variety of learning and instructional settings. An online course was designed using a knowledge-building *Community of Practice* (CoP) learning environment. A community is defined as a group of individuals who share experiences, learn together, and engage in regular interaction though discussion and knowledge sharing activities relevant to their domain. An online CoP may foster a high level of student interaction through group discussions and collaborative activities (Draper, The instructional effects of knowledge based communities of practice learning environments on student achievement and knowledge convergence. Ph.D. dissertation, Pennsylvania State University, 2010). In a moderated online instructional setting, graduate students collaborated and shared information to construct digital knowledge maps of instructional technology theories and concepts, which represent a shared meaning of complex theoretical concepts and content. This newly shared meaning represented knowledge convergence. This chapter begins by describing knowledge management, digital knowledge maps, communities of practice, and facilitator best practices, and then provides a document review and content analysis approach to evaluate the artifacts to determine common themes. Finally, suggestions and future research are provided.

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1 Introduction

What collaborative instructional strategies will promote knowledge convergence in digital environments? This is just one of many questions to address when designing college-level courses. Instructional Technology student populations consists of graduate-level students from varying professional backgrounds such as established teachers, technology specialists, researchers, instructional designers, corporate trainers, and from multicultural backgrounds. Technology has influenced the way courses are designed and delivered. There are two central challenges facing instructors today: the dynamic nature of technology, and the complexity and expansion of a field as a result of technological innovation and evolution.

Technological innovation influences research, behavior, instruction, design, delivery, expectations and expansion of a field of study. Across disciplines, there is pressure to utilize engaging and meaningful instructional strategies to help scaffold learners in the acquisition, organization, and management of knowledge. This chapter discusses the use of digital knowledge maps as a cognitive tool for the management of knowledge. The process of collaboration in group discussions and negotiation of concepts in the creation of digital knowledge maps promote the convergence of group mental models which are reified as external representations in the form of digital knowledge maps.

The goal of this chapter is to discuss instructional strategies that promote knowledge convergence through the use of digital knowledge maps within an online knowledge-building Community of Practice (CoP) learning environment. This exploratory research focuses on the facilitation, application, and structure of an online CoP learning environment and the use of the knowledge mapping application, Cmap Tools (http://cmap.ihmc.us/) to enhance knowledge management, convergence, and meaningful learning. This work is currently framing the author's pilot research in terms of how Cmap Tools can be utilized by teachers and instructional designers to facilitate knowledge management and knowledge convergence through the process of collaboration.

2 Knowledge Management and Digital Knowledge Maps

Knowledge management is the process of capturing and storing knowledge using a wide array of strategies and practices. For the purposes of this discussion, knowledge management efforts focus on educational objectives such as mastery of concepts, sharing knowledge, integration and generalization of concepts, and continuous knowledge building of the academe. An important element of knowledge management is knowledge portability and the development of academic memories. Knowledge portability allows for the capture (individually or in groups) and reapplication of knowledge artifacts. Much of the knowledge portability is predicated on the construction of knowledge repositories or academic memories.

Concept maps were developed in 1972 as a result of Joseph Novak's research based on David Ausubel's work on meaningful learning on the changes in children's knowledge of science (Novak & Musconda, 1991). An essential part of knowledge management is knowledge or concept mapping, which has been used in all aspects of training and education. "Concept maps are graphical tools of organizing and representing knowledge" (Novak & Cañas, 2008, p. 1). Typical concept maps contain shapes with key words or concepts and connecting lines often with directional arrows that represent relationships among the various words or ideas. Prepositions on the connecting lines are "linking words" or cross links between two or more concepts. Essentially, they are networks of concepts linked by phrases to show the relationship between concepts, which can be either causal or temporal. Novak (1977, 1998) suggested that knowledge creation is a high level of meaningful learning accomplished by individuals or groups who have a well organized knowledge structure in the particular domain of knowledge and have a high emotional commitment to persist in finding new meanings.

One way to increase knowledge transparency in groups and communities is by creating knowledge maps. Knowledge maps provide systematic access in the identification and sharing of critical knowledge. Probst, Raub, and Romhardt's model (2002) "Building Blocks of Knowledge Management" identified six building blocks described in Table 17.1. The six building blocks form the inner cycle of knowledge management. The table provides an explanation of each element and how it was applied in the digital knowledge mapping process.

Two additional elements form the outer cycle of the knowledge management cycle: knowledge goals and knowledge assessment. These elements directly relate to the design, development, and facilitation of instructional strategies as depicted in Table 17.2.

According to Probst's et al. model (2002), knowledge goals are broken down into three distinct areas: normative, strategic, and operational. Normative knowledge goals relate to the creation of community within groups to promote the preconditions for a culture of knowledge sharing and development. The overarching knowledge-building CoP learning environment provided the structure and student support for group culture nurturing and sustainability. Some instructional strategies used in this pilot study to foster normative knowledge goals was the use of a knowledge-building CoP learning environment, team-building activities during the initial face-to face class for community building and group selection. Each group collaborated to complete a learning team charter. The charter detailed each student's skill strengths and weakness, areas for improvement, group roles, and conflict management which became a learning "contract."

Strategic knowledge goal identification is an element of course development that identifies and defines the competencies needed for student success. Instructors use strategic knowledge goals to guide students through the content in a logical,

Table 17.1 Probst's et al. model (2002) inner cycle of the "Building Blocks of Knowledge Management" model

Knowledge management	Explanation	Application
Knowledge identification	An individual meta-cognitive activity. The process is finding knowledge in one's mind that is relevant to the learning task or objective.	Students construct their own knowledge map that can be evaluated for relevance in collaborative activities.
Knowledge acquisition	An individual or group process. The process is to determine what forms of knowledge/expertise should the individual or group acquire through relationship with others in collaborative activities.	Students identify knowledge gaps and work collaboratively to find knowledge and resources to fill the gaps. Digital knowledge maps help students visually search and store knowledge resources.
Knowledge development	Complements Knowledge Acquisition. Making sense of information and generating new knowledge. New knowledge is generated by integration, organization, and linking knowledge with application in contexts.	Students work collaboratively to elaborate, reorganize, fine-tune, and reformat existing knowledge structures. Digital knowledge maps help students to negotiate knowledge, concepts, resources, and links.
Knowledge distribution	An individual and/or group process. Knowledge sharing from individual to group and using knowledge in other contexts. Knowledge is communicated from instructor to student, between students, and from student to instructor.	Students work collaboratively to construct and communicate knowledge to create a shared representation or convergence of knowledge.
Knowledge utilization	External representations of knowledge are structured and represented task appropriately.	Students must construct digital knowledge maps that explicitly represent knowledge elements must be easily tracked and available.
Knowledge preservation	An individual or group process. The intentional selection of information and artifacts. Knowledge accessibility for future use. Organization of knowledge in a format that reflects the content or situation in a literal sense.	Students and groups use digital knowledge maps as a tool in knowledge management. Students represent the knowledge in a procedural or pragmatic format. Digital knowledge maps allow the inclusion of video, graphics, text, and hyperlinks that are organized in such a fashion that it makes sense.

Table 17.2 Probst's et al. model (2002) outer cycle of the "Building Blocks of Knowledge Management" model

Knowledge management	Explanation	Application
Knowledge goals	Instructor activity in the course design and development process. This process incorporates overall student learning outcomes and uses data from Knowledge Assessment to improve the quality of the instruction.	Instructors identify overall knowledge goals and objectives using Digital Knowledge Mapping as an instructional strategy to build highly interactive collaborative activities.
Knowledge assessment	An instructor activity that provides information about the reification of student/group knowledge convergence. Assessment must link to the Knowledge Goals. Assessment indicates course design effectiveness and provides useful information for future design iterations.	Digital Knowledge Maps provides instructors a visual representation student group knowledge convergence. Assessment of student/group digital knowledge maps provides gaps in content and resources for course improvement.

coherent fashion to ensure students meet core competencies identified in the course syllabus. Utilizing knowledge assessment data, instructors are able to determine desirable student outcomes for the future and hence are a segment of the course design process.

Operational knowledge goals ensure that the normative and strategic knowledge goals are actionable, tangible, and measurable. An operational knowledge goal example is the instruction and practice using a specific technology like Cmap Tools, the accessibility of resources and documents relating to weekly content and the opportunity to utilize the use of digital knowledge mapping activities to operationalize the learning goals established by the instructor.

3 Knowledge Convergence

Technology has enabled institutions to focus on learning spaces that blend social elements and technology specifically designed for collaborative learning (Norberg, Dziuban, & Moskal, 2011). The increasing proliferation of technological devices with connection to the Internet have enabled universities to develop online and blended courses that encourage individual and group learning in digital environments that foster the convergence of knowledge. "Computer Supported Collaborative Learning (CSCL) aims to afford knowledge construction and convergence in the context of collective activities supported by Computer Learning Environments (CLE)" (Romero & Lambropoulos, 2011 p. 312). The authors' research suggests that self and coregulation are necessary elements in the knowledge construction and convergence process. Robey, Khoo, and Powers (2000) argued that when learning is removed from where it is applied then it is less effective than when learning is situated. With this in mind, the design of the knowledge based CoP learning environment coupled with the digital knowledge mapping activities situated the learning in the online environment. In a sense, the design of the CoP course enabled the effective transfer of knowledge from one individual to another and to the collective.

Weinberger, Stegmann, and Fischer (2007, p. 1) define knowledge convergence as the “learners becoming more similar to their learning partners with regard to the extent of their individual knowledge.” Developing a shared knowledge means that “learners have the knowledge of the very same concepts as their learning partners.” Jeong and Chi (2007) define convergence as the outcome of a process by which two or more people share mutual understanding through social interaction. De Lisi and Goldbeck (1999) state that learners who collaborate influence one another when learning together.

Monereo’s (2009) definition of knowledge convergence closely aligns with Jeong and Chi’s (2007) definition. Monereo further explained the three different levels of knowledge sharing that correspond to varying knowledge convergence levels: consensus knowledge, common ground, and common knowledge. The three levels correspond to specific measurable levels of knowledge convergence (low, medium, and high). The lowest level of convergence, consensus knowledge, suggests a minimum level of convergence. This stage is rather shallow and includes sharing activities that include sharing information, clarifying understanding, and exchanging information without the transformation of an individual’s perspective.

The medium level of convergence, common ground, is described as shared cognitive perspective. Common ground is dependent upon interaction that creates mutual understanding, beliefs, knowledge, and assumptions. This is accomplished by the exchange of information by students in the learning environment. The exchange of information through the completion of learning activities promotes shared meaning within the group. Common ground infers awareness of the knowledge of others but does not change knowledge structures of one’s own knowledge.

Unlike common ground convergence, common knowledge convergence is the knowledge known by group members (Jeong & Chi, 2007). The highest level of convergence means that there are similarities in-group mental models that require deep individual high-level processing. Through interaction, individuals influence one another to achieve knowledge convergence. The CoP community element directly influences the outcome of knowledge convergence. A Community of Practice consists of a group of people who share prior knowledge and experiences as well as possessing prior unshared knowledge (Wenger, 1998a, 1998b). Collaboration with community members fosters the exchange of shared and unshared prior knowledge so that the community becomes similar in knowledge representations and group mental models. Fischer and Mandl (2005) stated that learners who converge in knowledge benefit more from collaborative learning than learners who do not engage in collaboration. One goal of a CoP is for individuals to converge or become more similar in thought through socially shared meaning.

Situated learning is a theory of knowledge acquisition whereby the learner gradually acquires knowledge and skills learned from experts in the context of day-to-day activities, social interactions and collaboration. Knowledge convergence is evident in communities of practice, specifically, the knowledge learned from others. Weinberger et al. (2007) research conceptualizes the similarity of knowledge prior to collaborative learning activities as shared prior knowledge. CoP practice element defines a set of common strategies and shared values that determine the way a process or skill is performed. CoP group members intuitively share common knowledge, concepts, and experiences to build knowledge. As each member contributes to the group, others analyze and build on ideas. Scardamalia's (2002) knowledge-building principles, in particular idea improvement, is evident in the outcome of knowledge convergence whereby individuals share the knowledge by contributing through dialog so that the others can integrate knowledge and add a new idea or element to improve on other's knowledge. Knowledge convergence in action is evident in the "transaction" of information. Teasley, (1997) states that transactivity is the degree to which learners refer and build on others' knowledge contributions and has been found to be positively related to individual knowledge acquisition in collaborative scenarios. Collaboration is the action among students that fosters the sharing of an individual's knowledge with others in the group to achieve knowledge convergence.

Weinberger et al. (2007) research suggests that knowledge convergence can be measured quantitatively. The analysis of knowledge convergence considers the dependency on how and what is being assessed. Evidence of convergence is measured in a meaningful context not by declarative knowledge tests. Assessing learners in the application of concepts within, complex contexts such as digital knowledge mapping is an appropriate measure of a group's knowledge convergence.

4 Communities of Practice

Social anthropologist, Jean Lave and social learning theorist Etienne Wenger first introduced the term community of practice (CoP) in 1991 to describe a group of individuals who share similar interests and through interaction and activities collectively develop new practices and knowledge. Lave suggests that the "relationship between human thought, human action, and the environment is so tightly interwoven that the mind cannot be studied independently of the culturally organized settings within which people function" (Hewitt & Scardamalia, 1998, p. 75).

As the first knowledge-based social structures, CoPs are not a new phenomenon. They have been in existence for many centuries. Lave and Wenger (1991, p. 47) described a CoP as "a set of relations among persons, activity and world, over time and in relation with other tangential and overlapping communities of practice." Socialization among members is a key component to the success of a CoP. "The central feature of CoPs is the relationships that develop between their members; it is here that the key to understanding the softer aspects of knowledge can be found" (Kimble & Hildreth, 2005).

Characteristics of CoPs vary. However, there are three essential elements: domain, community, and practice (Lave & Wenger, 1991). The domain of knowledge focuses on a shared interest that relates to members' interests and provides the community value and purpose. "The domain of the community is the *raison d'être*" (Wenger, McDermott, & Snyder, 2002, p. 31). Members' shared interest provides the motivation to discuss and share what is most important to the community and guides the way knowledge is organized. "A domain is not an abstract area of interest, but consists of key issues or problems that members commonly experience" (Wenger et al., 2002, p. 32). The domain is the center of gravity though its boundaries are permeable due to shifts in member focus. "Over time, they develop a unique perspective on their topic as well as a body of common knowledge, practices, and approaches. They also develop personal relationships and established ways of interacting" (Wenger et al., 2002, p. 5).

Wenger et al. (2002) argue that the second element, community, is "critical to an effective knowledge structure" (p. 34). A community is defined as a group of individuals who share experiences, learn together, and engage in regular interaction through discussion and knowledge sharing activities relevant to their domain. The community is the social fabric of learning where mutual respect, goodwill, trust, and communal identity are intertwined to build interpersonal relationships that promote a sense of belonging. Through regular interaction, members begin to increase collective domain knowledge and acquire individual knowledge and skills. "Over time, they build a sense of common history and identity" (Wenger et al., 2002 p. 35).

The third element, practice, is the engine that drives knowledge, fuels critical reflection, and fosters social identity. "Practice denotes a set of socially defined ways of doing things in a specific domain: a set of common approaches and shared standards that create a basis for action, communication, problem solving, performance and accountability" (Wenger et al., 2002, p. 38). Practice is steeped in the past however, directed toward the future. Members share real world experiences, challenges, stories, tools, and techniques to build and apply new knowledge through interaction and collaboration. Membership implies a level of competence or a baseline of common knowledge as the foundation for which members are able to use their individual perspectives to build knowledge and effectively work together. The community uses activities like brainstorming and negotiation to create new processes, and tools through ongoing interactions for validation of new knowledge. It is important for members to share implicit and explicit knowledge and experiences so that individual members construct their own knowledge. Essentially, a community operates in a living curriculum. Lave and Wenger (1991) suggested the learning that occurred in these CoPs is a form of "socialization into a community, where the newcomer gradually becomes a legitimate member of the community by learning the practice, language and conventions of the community through interaction with its established members" (Kimble & Hildreth, 2005, p. 3). In this sense, "learning is viewed as a situated activity and has as its central defining characteristic a process called Legitimate Peripheral Participation (LPP)" (Lave & Wenger, 1991, p. 92). There is an important connection between individual learning and social identity. Within a CoP, members learn by acquiring new knowledge through a lens of how the member sees the world, based on beliefs and past experiences, and how others see the member. Brown and Duguid (2001) suggested that what individuals learn always and inevitably reflects the social context in which they put it into practice.

A *knowledge-based Community of Practice* is a type of learning environment intended to codify and convert valuable, tacit knowledge into explicit knowledge. The reification process results in a collection of permeable repository of knowledge that can be shared by others in the Community of Practice. Knowledge based CoPs are the vehicle in which its passengers are able to propel the advancement of collective knowledge to develop individual skills and practices by achieving full participation of the members. The following section details the characteristics of knowledge-based Communities of Practice.

4.1 Tacit/Explicit Dimensions of Knowledge

"The knowledge of experts is an accumulation of experience – a kind of residue of their actions, thinking, and conversations" (Wenger, 1998b, p. 9). Explicit knowledge is easily articulated and takes a "hard" form such as documents, websites, podcasts, videos, spreadsheet data, and manuals that can be shared, and transferred to others within a group. In the classroom, explicit knowledge such as a text book is used as a learning tool to influence an individual's knowledge. While these tools are helpful to document knowledge for the individual or group, explicit knowledge is dependent upon tacit knowledge to be truly effective. Tacit or implicit knowledge has an inarticulate component that is the result of how individuals obtain this type of knowledge, which is mostly contextualized, personalized, and acquired through practice and experience and socialization.

Tacit knowledge puts explicit knowledge into practice. Tacit knowledge is present the classroom and described as "know how" transferred by storytelling, conversation, and narrative. "It is quite possible to acquire a tool but to be unable to use it" (Brown & Duguid, 2001, p. 33). The importance of the "know how" or tacit knowledge, "to use a tool involves far more than can be accounted for in any set of explicit rules" (Brown & Duguid, 2001, p. 33). Instead, such activities are framed by a set of cultural assumptions and practices Brown, Collins, and Duguid (1989). It is challenging to use a tool appropriately without understanding the community or culture in which it is used.

The use of concept maps to help create meaningful learning is supported by Vygotsky's (1928, 1979) positions on the importance of social interaction in learning. Lev Vygotsky's theory of cognitive development suggests the importance of social interactions in the development of human intelligence. He argues that the higher cognitive function or consciousness is the product of socially meaningful activities and that an individual's mind is created from social interactions through observation. His work "stresses that individual intelligence emerges as a result of biological factors that interact with physical and especially a social environment through a developmental process" (Lindblom & Ziemke, 2003, p. 80).

According to Vygotsky (1934, 1978) there are elementary and higher levels of mental function. Elementary mental functions are inherent in a human or animal and are referred to as signalization. Signalization is the direct link between the stimulus and the response that is limited to simple memory, attention, and other rudimentary sensory functions that lack thought. Vygotsky further postulates that higher mental function is an exclusively human phenomenon and is a direct result from human interaction. Higher mental function requires an intermediate step such as language or other psychological tools that generates thought in an individual to bridge the path between the stimuli that result in a different response. There are two levels that comprise the higher mental function: the interpsychological level is the interaction between people, and the intrapsychological level is the interaction within the individual. An individual has the ability to behave in a certain manner through observation and integration of knowledge both deliberately and unconsciously.

The internalization process is related to Vygotsky's theory, Zone of Proximal Development (ZPD) where the transformation of interpersonal functions to intrapersonal function occurs. The individual learns through the interactions with others to use psychological tools in order to acquire and integrate knowledge. The zone represents the "distance" between an individual's actual level of independent problem solving and the level of potential ability to problem solve under supervision or in collaboration with more capable people. In this respect, Lave's (1988) apprenticeship learning theory and the relationship between the novice and master is similar to Vygotsky's concept of ZPD.

5 Method

The argument of this study is supported by the idea that collaboration through knowledge mapping activities in a CoP learning environment has a central role to play in knowledge convergence and meaningful learning. Additionally, this work is currently framing the authors' pilot research in terms of how Cmap Tools can be utilized by teachers and instructional designers to facilitate knowledge management and knowledge convergence through the process of collaboration.

5.1 Participants

The participants for this study included 20 graduate-level students (13 female, 7 male) at varying levels of graduate study (9 doctoral, 11 master) at a North American university. Students' major emphases of study are: Literacy Education (1) Adult and Higher Education (2) and Instructional Technology (18). All graduate students in the Instructional Technology program must successfully complete the course in order to graduate from the program.

5.2 Research Context and Materials

The ProSeminar class in Instructional Technology is the foundation course for the Educational Technology Program. Students are required to complete this course early in their academic career. The Department and College Curriculum Committee approved the content. The 15-week course was originally developed for traditional, face-to-face delivery. As technology has evolved, the course was redesigned into a blended, accelerated 7-week format. The following topics are included:

- The Instructional Technology field and definition
- Learning Theories
- Instructional Design Models
- Social Learning
- Informal Learning
- Literature Review and Annotated Bibliography

Each week focused on a specific concept. The students were required to complete individual and group activities. Individual assignments included a reflective response to a forum question, responding to other students' postings, submitting an annotated bibliography on the weekly concept and writing a reflection paper. Group activities included collaboration on the creation of five digital knowledge maps and a group literature review.

The ProSeminar in Instructional Technology course was developed and designed to operate in Moodle (Modular Object-Oriented Dynamic Learning Environment). Moodle (https://moodle.org/) is an open source Learning Management System application developed and maintained by a consortium of educators to promote constructivist pedagogy. Moodle's functionality offers many features for the design of online instruction. Instructional designers have the ability to create comprehensive, content-rich, highly collaborative learning environments that complement the CoP elements.

5.3 Instructor Activities That Support Learning

The instructor plays a pivotal role in the success of a community of practice learning environment. The traditional instructor role of "sage on the stage" is no longer effective in the online environment. Rather, the instructor becomes a coach, mentor, learner, and champion in the community. Wilson, Ludwig-Hardman, Thornam, and Dunlap's (2004) research on bounded learning communities suggested that the instructor must have a teaching presence within the online community. The instructor's role includes modeling knowledge construction, troubleshooting and resolving problems, monitor learning, use meaningful instructional strategies and establish trusting relationships with students. The following facilitation strategies were implemented in the delivery of the ProSeminar in Instructional Technology course.

Precourse activities. One week before the class began, a welcome letter was sent to the students that detailing course content, login instructions for Moodle, and instructor expectations. The students were required to create a "digital introduction" and post their presentation in a designated discussion forum in Moodle before the start of the semester. One instructional strategy employed in the course was the use of Cmap Tools to create concept maps. The Unified Theory of Acceptance and Use of Technology (UTAUT) instrument was administered to determine student behavioral intent in the use of knowledge mapping technology. The results determined the increase or decrease of instructor scaffolding activities and resources to help promote the use of the concept mapping application. Venkatesh, Morris, Davis, and Davis (2003) developed and validated the UTUAT incorporating seven paradigms: performance expectancy, effort expectancy, and attitude toward using technology, social influence, facilitating conditions, self-efficacy, and anxiety.

Course activities. The first class meeting focused on team-building skills. Each group completed a team charter that inventoried student strengths and weakness, contact information, areas for growth, roles, and a conflict management process. Essentially, the team charter became a learning contract between the students and a mediation tool for the instructor. During the first class meeting students downloaded Cmap Tools and started working with the application. Additional resources were uploaded in Moodle to provide ongoing support for mastering Cmap Tools. After each collaborative knowledge mapping activity, the students completed a Team Assessment and Diagnostic Instrument (TADI) that measured general types of knowledge. The empirically validated tool is shown to be strong indicator of a group's shared cognition and also determines if team intervention is needed. "The TADI was specifically created to measure the degree of team-related knowledge in order to determine team-related knowledge sharedness" (Johnson, Silkorski, Mendenhall, Khalil, & Lee, 2010, p. 338). The instrument is segmented into five factors: general task and team knowledge, general communication skills, attitude toward team and task, and team resources and working environment. The results provided the instructor with an indication of team processes and team performance. The data for each factor and combined factors can be used to determine the type of intervention that is most appropriate.

Support for knowledge map creation. Novak's (1977) research on concept mapping for children suggests two different techniques to start concept mapping activities: focus question and a list of concepts called the "parking lot" and using an expert concept map for more complex knowledge. For the purposes of this study, the researchers used a modified version of the former technique that utilized a focus question without the parking lot. In addition to the focus question, a number of readings or web resources were provided to start the process of the creation of knowledge maps.

6 Results and General Discussion

The goal of this chapter was to demonstrate instructional strategies that promote knowledge convergence through the use of digital knowledge mapping within an online knowledge-building Community of Practice (CoP) learning environment. This exploratory research focused on leveraging the knowledge mapping application, Cmap Tools to enhance knowledge management and group convergence. The following section will discuss the results of the UTUAT instrument and the emergent themes and evolution of group digital knowledge maps.

6.1 UTUAT

The four constructs of the UTUAT instrument: effort expectancy, performance expectancy, social influence, and attitude are hypothesized to have a significant impact on user acceptance and behavioral intent. The highest student response average rating for effort expectancy in “learning to use knowledge mapping technology is easy” statement shows 4.52 and “it is easy for me to become skillful at using Knowledge Mapping Technology” statement shows 4.48 which indicates that the students perception to the degree of simplicity associated with the knowledge mapping technology is high (Fig. 17.1).

The highest student response average rating for performance expectancy in “using knowledge mapping technology increases my chances of producing quality work” statement shows and average rating of 4.71 and “using knowledge mapping technology increases my productivity” and “I find knowledge mapping technology useful in my day to day job tasks” statements shows an average rating of 4.67 which indicates that the students perception to the degree to which students believe that

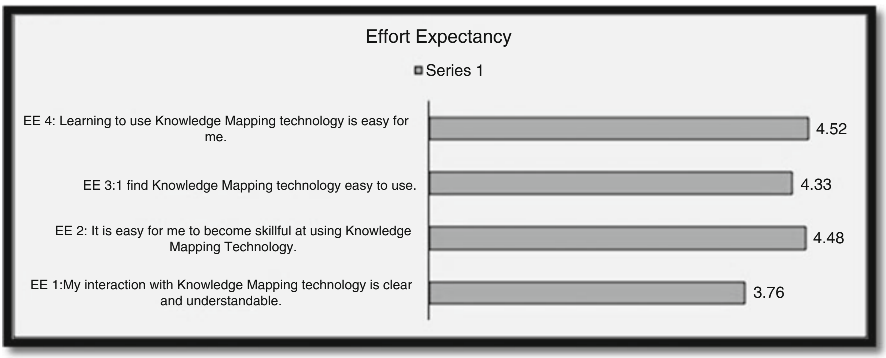

Fig. 17.1 Effort Expectancy (EE) The degree of simplicity with the use of Knowledge Mapping technology

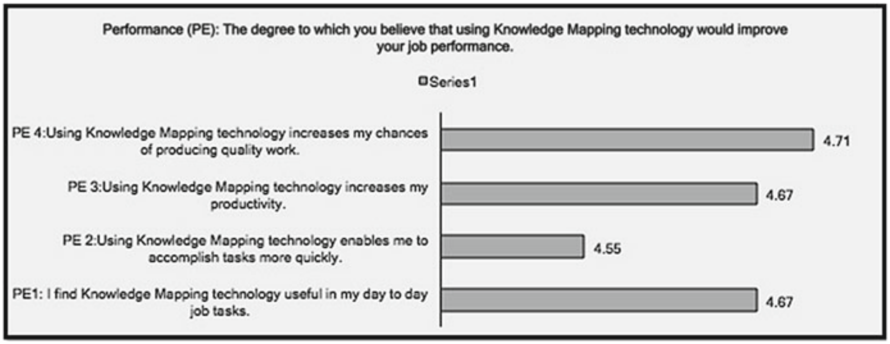

Fig. 17.2 (PE) Performance expectancy

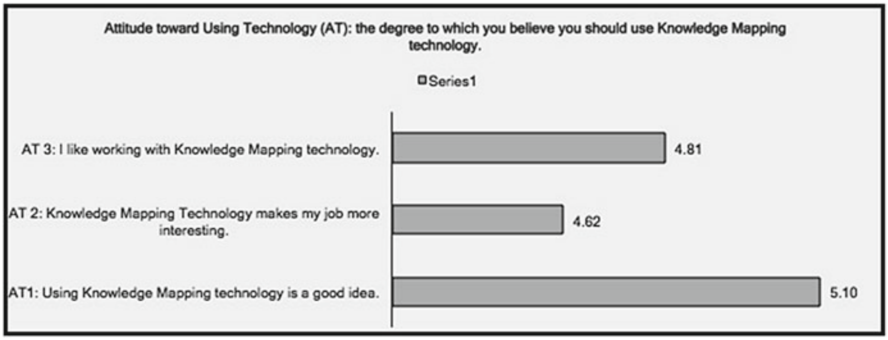

Fig. 17.3 (AT) Attitude toward using technology

using knowledge mapping technology would improve their performance is high. However, students responded lower to the statement "using knowledge mapping technology enables me to accomplish tasks more quickly" with an average rating of 4.55 which indicates that the students' perception is that knowledge mapping activities increase performance but takes longer to complete (Fig. 17.2).

The highest student response average rating for attitude toward using knowledge mapping technology in "using knowledge mapping technology is a good idea" statement shows an average rating 5.10 and "I like working with knowledge mapping technology" statement shows an average rating 4.81 which indicates that the students the degree to which students believe they should use knowledge mapping technology is high (Fig. 17.3).

The highest student response average rating for the social influence category in "people who are my superiors think that I should use knowledge mapping technology" statement shows an average rating 3.33 and "people who influence my behavior think that I should use knowledge mapping technology" statement shows

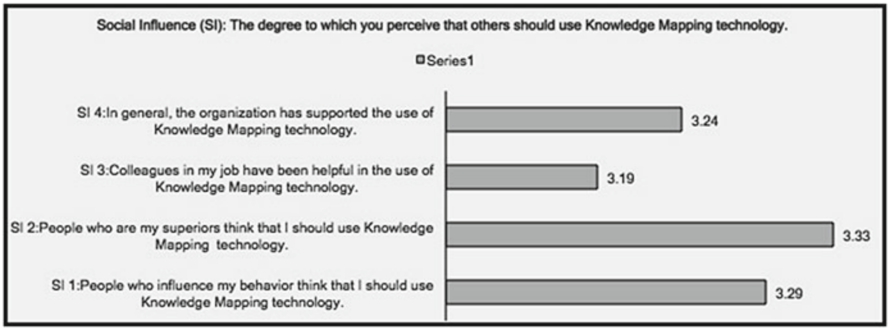

Fig. 17.4 (SI) Social Influence

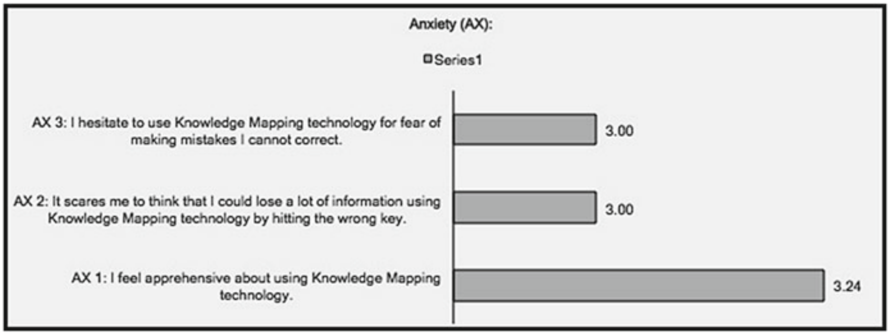

Fig. 17.5 (AX) Anxiety

an average rating 3.29 which indicates that the students perception to the degree of to which their instructor should use knowledge mapping technologies (Fig. 17.4).

The highest student response average rating for anxiety in "I feel apprehensive about using knowledge mapping technology" statement shows an average rating of 3.24 and "I hesitate to use knowledge mapping technology for fear of making mistakes I cannot correct" and "It scares me to think that I could lose a lot of information using knowledge mapping technology by hitting the wrong key" statements shows an average rating 3.00 which indicates that the students' anxiety regarding the use of knowledge mapping technology is low (Fig. 17.5).

Students' intent to use knowledge mapping technology in the future is high. The highest student response average rating for behavioral intent in "I predict I would use knowledge mapping technology in years to come" statement shows an average rating 5.00 and "I intend to use knowledge mapping technology in the next year" statement shows an average rating 4.81 (Fig. 17.6).

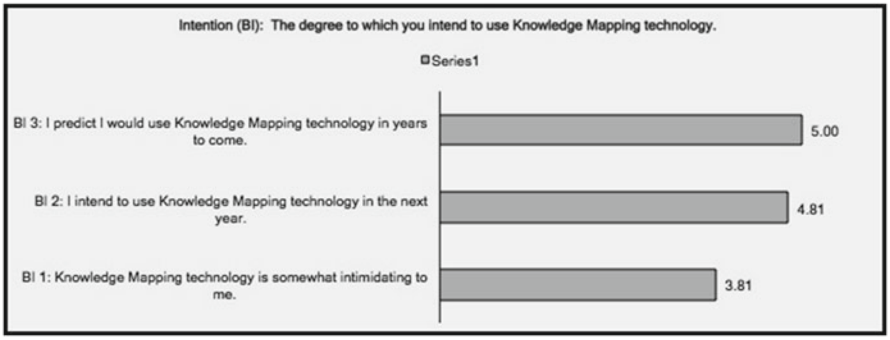

Fig. 17.6 (BI) Behavioral intent

6.2 Digital Knowledge Map Analysis

"Cmap Tools supports the construction of 'knowledge models': sets of concept maps and associated resources about a particular topic." (Cañas, Hill, & Lott, 2003 p. 2) Digital knowledge map creation emphasizes relating new knowledge to the student's existing knowledge structures to facilitate meaningful learning. This section provides a discussion of the researchers' observations of the common themes and evolution of the characteristics of group digital knowledge maps throughout the semester.

Thematic content was derived from widely varying concept map designs by searching for commonalities and taking simple counts of concepts addressed as well as through use of a matrix rubric developed as themes emerged from the analysis. Rubric analysis of the content was required by hand since concept maps do not readily lend themselves to software applications for qualitative analysis. Moreover, the manageable amount of data permitted an informal approach to coding while larger amounts of data would have demanded more complex approaches. The following tables provide a list of knowledge map concepts broken down by group.

All group knowledge mapping activities were prompted by a focus question. Students worked collaboratively to create a knowledge map that relates to the week's topic. The first knowledge map developed by the groups was created during the first class session. The simple knowledge map is an example of Monereo's (2009) lowest level of convergence which is consensus knowledge and suggests a minimum level of convergence. The students shared information and exchanged information without the transformation of an individual's perspective (Fig. 17.7).

The groups worked collaboratively to define the Instructional Technology field. Figure 17.8 below represents an example of the simplicity of the group's mental model of the topic and creation of the first Cmap.

All five groups converged on a link to learning theories, ethical practice, instructional design models, and professional practice in response the focus question: Define the Instructional Technology field. The data shows that many concepts were

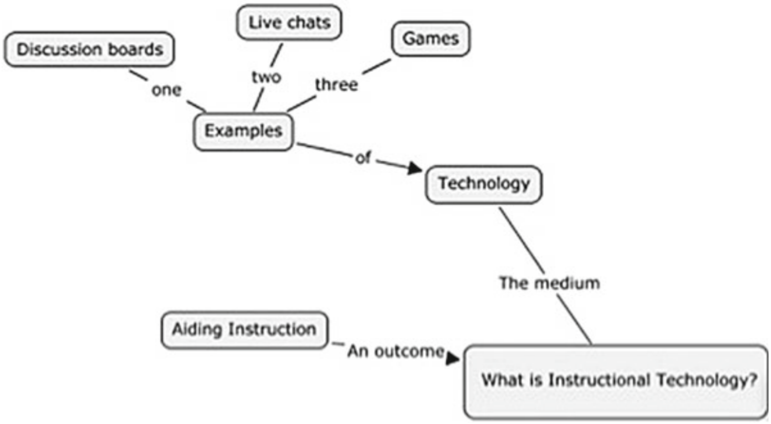

Fig. 17.7 Example of pretest knowledge map

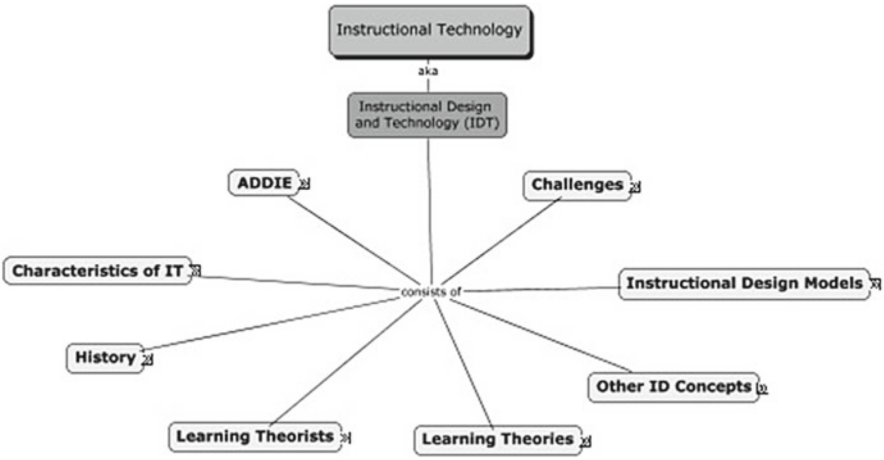

Fig. 17.8 Example of topic one group knowledge map

shared among the groups with the "history" concept consistent across all five groups (Table 17.3).

The number of concepts range from six to eight nodes. The knowledge maps represent a free-style format. It is interesting to note that some of the groups used a timeline format as shown in Fig. 17.9 to structure the knowledge maps while others used a hierarchical structure as shown in Fig. 17.10.

The second knowledge map activity focused on different instructional design models. The concept totals are low across the groups; however, groups two, four, and five referenced each other's theorists as influencers of their assigned ID model (Table 17.4).

Table 17.3 Topic one coding rubric for knowledge maps

Topic one: definition of instructional technology and field					
Themes	Group 1	Group 2	Group 3	Group 4	Group 5
Professional organization	1				
History	1	1	1	1	1
Instructional design					
Ethics	1			1	1
Instructional technology		1	1	1	1
Learning theories	1	1		1	
Analysis of performance problems	1			1	1
Instruction	1	1	1		
Contexts			1	1	1
Learners	1	1	1	1	1
ID Models	1	1	1	1	1
Total:	8	6	6	8	7

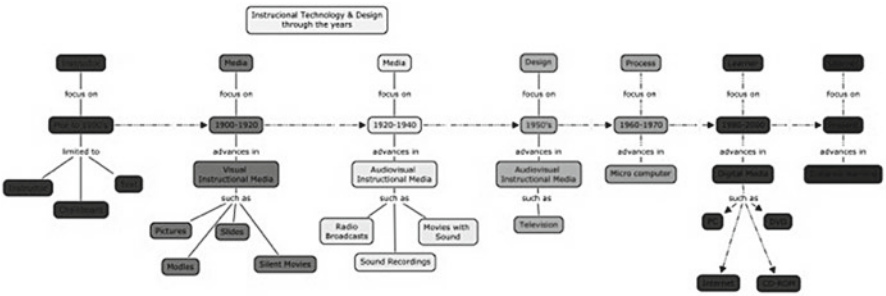

Fig. 17.9 Example of timeline structure

The sophistication of the group knowledge maps grew throughout the semester. As students' expertise with the software functionality increased additional elements such as color, shape, resources, and graphics emerged. The groups' knowledge maps indicate a medium level of convergence, or common ground, which is shared cognitive perspective. This is accomplished by the exchange of information by students in the learning environment. Common ground infers awareness of the knowledge of others but does not change knowledge structures of one's own knowledge (Table 17.5).

Over time, the knowledge maps became more complex in the number of concepts, links, cross-links, and prepositions. The knowledge map shown below is an example of a group knowledge map that shows a more complex representation of the topic that includes imbedded documents, graphics, hyperlinks, videos, and podcasts (Fig. 17.11).

The last knowledge map represented the highest level of concepts that overlapped across the groups. Concept nodes ranged from five to eleven primary nodes and included theorists and concepts that were consistent across groups (Table 17.6).

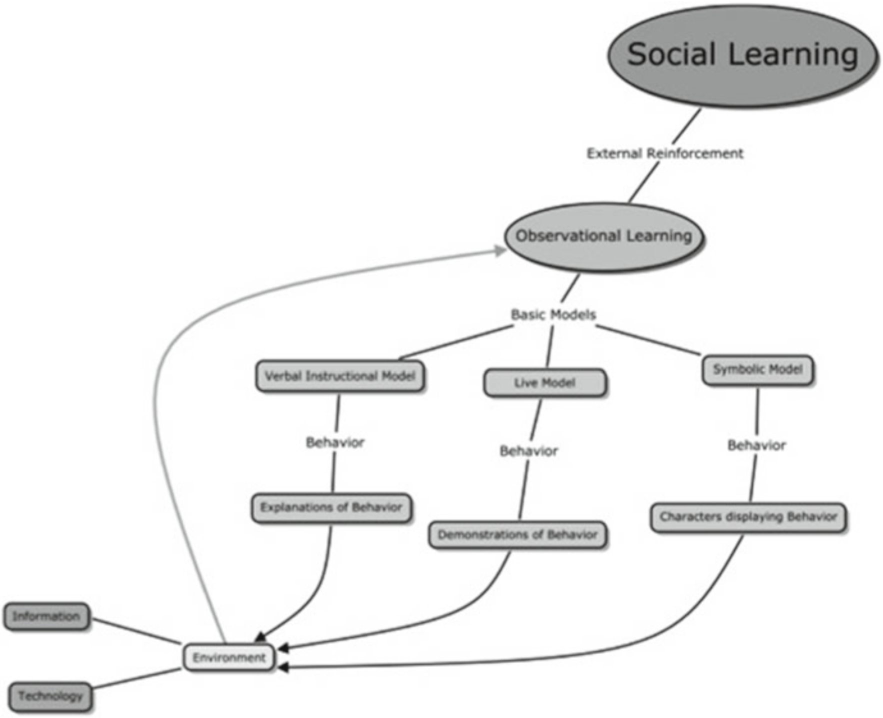

Fig. 17.10 Example of hierarchy structure

Table 17.4 Topic two coding rubric for knowledge maps

Topic two: instructional design models					
	Group 1	Group 2	Group 3	Group 4	Group 5
Gagne	1	1			
Understanding by design			1		
Dick and reiser				1	1
Dick and carey				1	1
ASSURE		1			
Categories of learning	1				
Learning events	1				
Systemic	1	1	1	1	1
Bransford					1
Total	4	3	2	3	4

Visual complexity, on the other hand, grew significantly as teams sought images to represent the various concepts. Figure 17.12 represents a knowledge map of Vygotsky's (1978) Zone of Proximal Development that uses graphics instead of concept nodes and text to represent cross-links.

Table 17.5 Topic three coding rubric for knowledge maps

Topic three: informal learning	Group 1	Group 2	Group 3	Group 4	Group 5
Informal learning	1				1
Nonformal learning	1	1			
Situated cognition			1	1	
Communities of practice				1	
Social learning	1		1	1	1
Constructivist		1			
Formal learning	1				
Incidental learning	1				
Context	1	1		1	1
Authentic activities		1	1	1	
Definition	1				1
Instructor		1	1		
Outcomes		1	1		1
Total	7	6	5	5	5

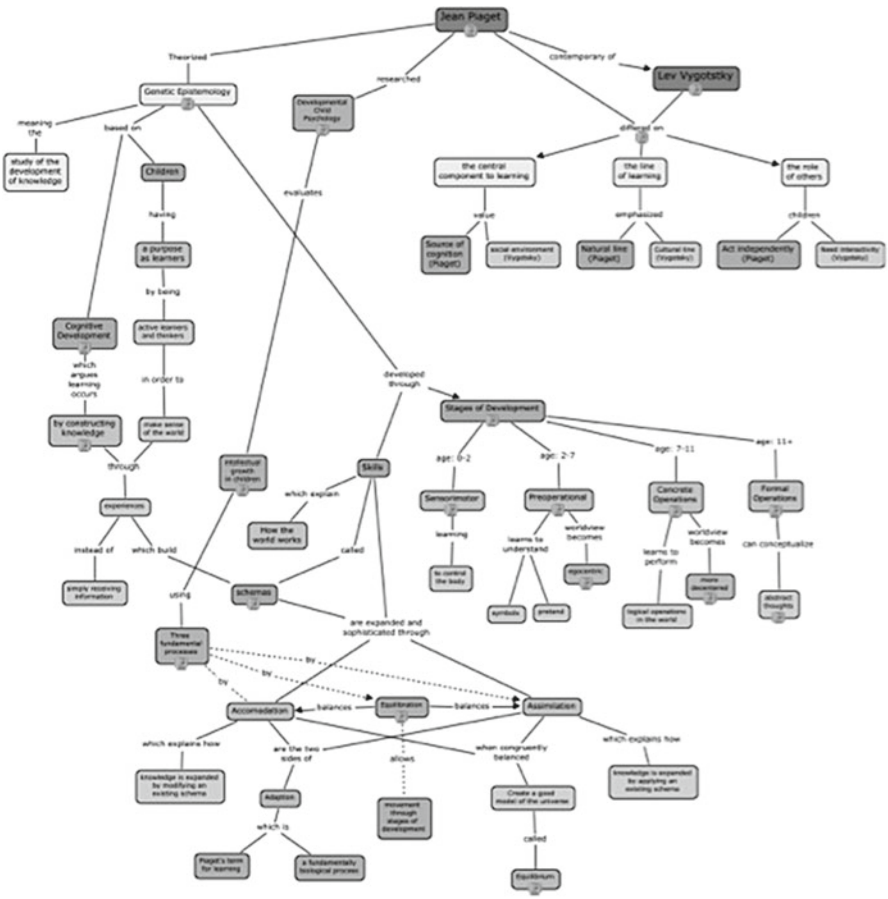

Fig. 17.11 Example increasing complex knowledge maps

Table 17.6 Topic four coding rubric for knowledge maps

Topic four: Vygotsky and Piaget					
	Group 1	Group 2	Group 3	Group 4	Group 5
Vygotsky	1	1	1	1	1
Piaget	1	1		1	
Social development theory	1	1		1	1
Elementary mental functions	1		1		
Knowledge development				1	1
Cognitive development	1			1	
Stages of development	1	1		1	
Higher mental functions		1	1		
ZPD	1		1		1
Developmental psychology				1	
Sociocultural approach	1				
Tools of intellectual development	1		1		1
More knowledgeable others	1		1		
Assisted performance					1
Individual performance					1
Language	1		1		
Inner speech			1		
Total	11	5	8	7	7

Instructor and individual team member checking added truthfulness to the data analysis (Glesne, 1999). Member checking activities include reviewing the knowledge maps and making interpretations that are brought back to the students to verify their perspective and to help the researchers develop new ideas or interpretations (Glesne, 1999, p. 152). Individual students' within the teams reviewed their maps independently and as a group and refined where necessary, working with the researchers to assure accurate interpretation. The teams then negotiated the final integrative concept map that coalesce the ideas of all five teams into a coherent whole that represented conceptual convergence on the core themes discussed above. The final class knowledge map complexity was seen to decrease as each group began to chunk concepts and develop more coherent schema for the data. More efficient use of Cmap functionality afforded the streamlining of concepts which utilized the "expand and collapse" functionality. Additionally, the highest level of knowledge convergence, common knowledge, was evidenced by the final class map. The highest level of convergence means that there are similarities in-group mental models that require deep individual high level processing.

6.3 Conclusion

Research on the design and development of online Communities of Practice is still emerging. Among the issues is "the evolutionary pattern of CoP development is poorly understood" (Schwen & Hara, 2003, p. 262). Schwen and Hara (2003)

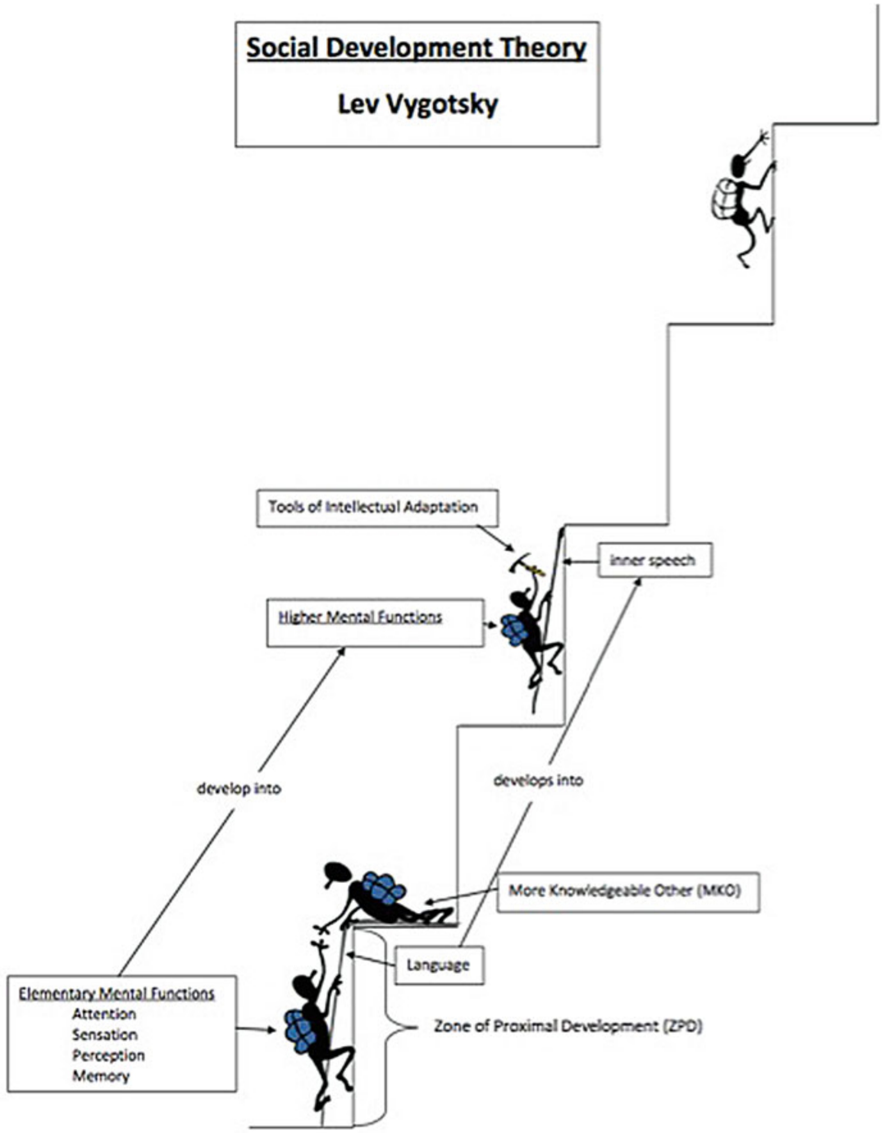

Fig. 17.12 Example of visuals instead of traditional nodes

suggested that Communities of Practice are fully functioning when they evolve over time, which makes them difficult to study. Questions also have been raised about the role of knowledge in Communities of Practice. Researchers have varied interpretations of knowledge, particularly with regard to knowing in practice, and hence it is worth studying. Schwen and Hara (2003, p. 263) stated "knowledge and knowing epistemologies are two distinct processes that require different designs to support optimal community learning."

Knowledge convergence is the common thread throughout this discussion. Instructional strategies such as digital knowledge mapping can foster communication and collaboration among students to develop and grow a thriving knowledge base. Instructors, who use online CoP learning environments as a vehicle to foster relationships, collaborate to build knowledge so that individuals and groups effectively share to achieve knowledge convergence. The evolution of the knowledge maps throughout the semester provides a visual representation of the three types of knowledge convergence as defined by Monereo (2009).

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Chapter 18
Shared Cognitions in a Field of Informal Education: Knowledge Maps Towards Money Management of Young Adults

Daniela Barry, Nina Bender, Klaus Breuer, and Dirk Ifenthaler

Abstract Prerequisite knowledge of first grade Bachelor students ($N=48$) on processes of private consumption and housekeeping (money management) has been assessed by means of knowledge mapping. The study is based on the fact that in German compulsory education, there is no emphasis on economic literacy. Young adults (students), however, have to cope with individual economic planning processes. Most of them succeed based on support from families, friends, and peers. Some may simply refer to successful models experienced within their money socialization or to professional advice. Others, however, fail and become confronted with early indebtedness or even overindebtedness. The percentage of young adults with debtor carriers is growing. That evokes the claim for teaching financial literacy through formal education within compulsory schools. Here, our research has its origin in the question for the knowledge base of young adults within the domain of financial literacy. For going beyond knowledge on the level of simple recall, an approach of knowledge mapping is used. The underlying hypothesis is that despite of the common reference (given by the task and the relations), there will be no shared conceptual structures due to the lack of shared cognitions from formal education.

Keywords Money management • Economic literacy • Financial literacy • Indebtedness • Knowledge map

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1 Objectives and Theoretical Background

Contrary to formal education, which requires concrete learning environments and didactic settings, informal education takes place without structure through conversations or media use for example. Financial literacy seems to belong to the field of informal education. This assumption refers to the finding of lacking financial contents in school curricula (s. BMAS, 2008; Gabanyi, Hemedinger, & Lehner, 2008; Krumpolt, 2008). Indeed, there are many programs and projects to further financial competences. But there is no consequent integration of these programs in the curricula of compulsory education in Germany. Schools with responsibility for vocational education and training consider financial contents for occupational fields such as business jobs. But it is still a debatable point whether these contents lead to an adequate level of financial literacy.

The term *literacy* includes complex processes of understanding and transfer, especially in pedagogical issues. Vitt (2000) defines *financial literacy* as the capability to know, analyze, and communicate about the own financial situation. This involves the ability to deal with financial decisions in a future-oriented understanding. Pang (2009, p. 3) amplifies this approach, which refers mainly to private situations, by focusing on macroeconomic topics also. Individuals should learn to understand and interpret economic data as well as analyze financial issues on the basis of relevant economic concepts and principles. But surveys from the USA, Asia, and Europe can prove a lack of financial literacy in nearly every age and social class. Therefore, Pang (2009, p. 3) claims the implementation of financial literacy standards in curricula. He defines central economic concepts for successful financial decisions. These core concepts are:

- Saving, consumption, and investments
- Risk, ROI, and solvency
- Opportunity costs
- Inflation and deflation
- Value and amortization

Mason and Wilson (2000, p. 31) define financial literacy as capability to gather, understand, and evaluate necessary information in the field of financial issues. Decisions shall be made by calculating optional consequences. Holzmann (2010, p. 4) offers the following definition of financial literacy or capability: “A financially capable person is one who has the knowledge, skills and confidence to be aware of financial opportunities, to know where to go for help, to make informed choices, and to make effective action to improve his or her financial well-being while an enabling environment for financial capability building would promote the acquisition of those skills.” It seems to be clear that on scientific landscape, definitions on financial literacy are unequal. Some of the mentioned ideas refer only to knowledge-based skills. Some definitions go further by including concepts of self-regulation such as “confidence.” This leads to methodic problems concerning the measurement of financial literacy. “Financial literacy can only ensure individuals are informed to make decisions, it cannot ensure the "right" decision is actually made" (Mason & Wilson, 2000, p. 32). It is obvious that knowledge based on financial facts is not enough to handle financial decisions properly. Individuals also need sophisticated abilities in terms of analyzing, interpreting, and transfer. The question is if these abilities are sufficient to reach an appropriate level of *financial competence*. Due to that, it is necessary to consider both terms as well as their contribution to successful money management. Recommendations considering the development of financial literacy or competence are directed towards the conveyance of financial knowledge in schools. In contrast, some surveys and reports point out that financial competence does not only includes knowledge but also social and motivational factors (Schufa Holding AG, 2008, p. 38). Furthermore, it is necessary to define a specific context in which competences take effect (Erpenbeck & von Rosenstiel, 2003, p. XII). Meanwhile, essential features of competence are defined by scientific consensus (Kaufhold, 2006, p. 21–25):

1. Action orientation
2. Relation to situation and context
3. Subject relations
4. Variability of competence

Winther and Achtenhagen (2010, p. 18) interpret the consideration of situation and context as the main challenge in the development of instructional tools for vocational education. Klieme, Maag-Merki, and Hartig (2007, p. 9) confirm the assumption of a multidimensional comprehension of competence. Education and qualification cannot only be described by knowledge, although it is clear that knowledge is a main factor of competence. People have to build joined-up thinking as well as the capability to handle in a self-regulated way. This includes autonomous learning, abilities in problem solving, and social and communicative skills. Klieme et al. (2007, p. 12) defines those capabilities as "correlated partial competences." The theoretical descriptions clarify the multidimensional comprehension of competence development. Formal knowledge is a main predictor to evoke financial literacy, but social and motivational factors as well as indicators of the setting need to be considered. These assumption leads to several questions in terms of financial literacy. First, there is the need to register the status quo of youth cognitions towards money management. Therefore, it is necessary to analyze the common thread of financial knowledge or perception. Second, it is of peculiar interest if there are differences between the perceptions of students with and without formal education in the field of business management. This comparison refers to the assumption that formal business education in vocational education generates more sophisticated knowledge structures in financial issues. Therefore, young students ($n = 48$) were asked to draw their individual knowledge or knowledge maps in terms of financial literacy, resp., money management. Half of them (24) finished a vocational training, 23 of them in the field of business management.

The current paper describes the mentioned study and the obtained results. It focuses on the field of knowledge towards financial spheres of activity. It is the aim to figure out differences and accordances within test persons' mental representations.

These representations were visualized through concept or knowledge maps.[1] Via content and structural analysis, a referential network shall be developed, which can be used as a comparison network for further studies. Below, the methodology of knowledge mapping is presented. Afterwards, the results of the pilot study are described and discussed.

2 Method

2.1 Knowledge Mapping as Tool to Diagnose Individuals' Knowledge Towards Money Management

2.1.1 Definition and Fields of Application

Knowledge maps are networks based on terms (concepts) as well as relations between them. The networks illustrate the individuals' knowledge structure from a specific issue, for example, the knowledge structure about money management (Stracke, 2004, p. 17). Basically, there are two main reasons to work with knowledge maps: first, as a matter of didactic arrangements to further students' structural knowledge and, second, as a tool to diagnose individuals' previous knowledge in a specific field. Contrary to classical testing procedures, the creation of a knowledge map needs a higher effort and therefore higher cognitive requirements. The test person has to title different concepts and to build interrelations between them. Furthermore, the test person has to decide about the direction of the relation (indegrees and outdegrees). Finally, all concepts and relations need to be summarized in a structural overall view. Using knowledge maps is linked to several principal benefits. The test person deals with a specific issue creatively and actively. The network structure corresponds to the mental representation referring to Ausubel's Assimilation Theory. Thereby, higher learning outcomes can be reached (Ausubel, Novak, & Hanesian, 1974). By structuring the network, the test person processes not only declarative knowledge but also procedural knowledge or empirical knowledge (Schnotz, 1994).

Apart from that, Stracke (2004, p. 26) argues that mental representations such as knowledge maps are simple images of abstract coherences and therefore not suitable to explain information processing. There are some more restrictions in terms of knowledge maps. To make a test person build a knowledge map, which means they are confronted with high cognitive demands for a while, it needs special incentives. Furthermore, it is necessary to give some instructions about the method in advance.[2] The effort to collect and analyze the data is high, especially in settings which permit

[1] Both terms are used as synonyms in this paper.

[2] Relevance and instructional hints to train concept mapping technique are described in the papers of Aprea (2001, p. 188–189).

free associations towards concepts and/or relations. Despite of the methodological restrictions, knowledge mapping seems to enable a useful approach to individuals' knowledge structures. In order to create curricula about financial issues, a prior diagnose of individuals' knowledge can be meaningful to identify structural holes[3] in cognitive systems (Jansen, 2003, p. 187–192). The following paper presents a pilot study with 48 first grade Bachelor students (B.Sc.) in the field of vocational education and training. This study submits an explorative approach to shared cognitions towards private financial processes and focuses on the relevance of formal education in terms of financial literacy. Besides, it shall be proved if the data collected is suitable to extract a referential network, which can be used as comparison network in further surveys.

2.2 Study

2.2.1 Research Design

The survey concerns 48 first grade students (Bachelor of Science in Vocational Education and Training) at the Johannes Gutenberg University in Mainz, Germany. Knowledge maps about individuals' perceptions of private money management were ascertained. The survey is conducted during the course "Introduction to Vocational Education and Training." Prior lessons within this course were addressed to the issue of knowledge mapping. Immediately before the survey, the test persons get a short method training. Afterwards, the test persons are confronted with a specific task:

> Terms like "Needs" and "Shortage" are common terms concerning economic decisions. Every person has to make economic decisions in its private life choices as well. Which concepts do you associate with these private economic decisions? What do you think is a conceivable relation between these concepts? How do assets or indebtedness occur? How does it happen, that indebtedness leads into personal insolvency? Please try to answer these questions by creating a knowledge map. Please label every concept you use. Please try to link the selected concepts as far as you perceive a relation and label the relations between two concepts also.

Concerning the creation of the task, it is known that a tight questioning can lead to problems for the test person in representing their knowledge, although it is clear that knowledge maps describe only partial knowledge. The task gives first impulses through its wording. To some extent, these impulses are reflected in the collected networks. The time frame to build the networks is scheduled broadly, so that every student has the chance to finish the task. After getting the task, students were asked to note every concept they associate with the issue. After that, they are supposed to build up propositions[4] and an entire network. The treatment takes place by classical

[3] The term "structural holes" refers to the analysis of social networks. But, it is useful to explain shared deficits in knowledge maps in the same way.

[4] Propositions are the smallest unit in a knowledge map in the format "term-relation-term" (Novak & Cañas, 2008, S.1).

Table 18.1 Open pool of relations

(C1) is equal to (C2)	(C1) leads to (C2)
(C1) promotes (C2)	(C1) gets (C2)
(C1) reduces (C2)	(C1) is responsible for (C2)
(C1) influences (C2)	(C1) exists as against (C2)
(C1) controls (C2)	(C1) determines (C2)
(C1) is greater than (C2)	(C1) should achieve (C2)
(C1) is less than (C2)	(C1) concludes (C2)
(C1) is part of (C2)	etc.

(C1) = concept 1; (C2) = concept 2

paper-pencil procedure. One main decision before using the knowledge mapping method is to choose between open and closed pools of concepts and relations or to allow the test persons to create concepts and relations by themselves without any prompts. With closed pools, test persons get a list with concepts and relations, and they have to build their networks by using them. They are not allowed to create alternative concepts or relations. Open pools offer a set of concept and/or relations, but the test persons may create other ones by themselves. On the one hand, prompts lead to a higher degree of comparability. On the other hand, it means an intervention into individuals' own representations (Stracke, 2004, p. 34–35). Although concepts and relations are given, it is necessary to be oriented towards the common language use (Fürstenau & Trojahner, 2005, p. 194). Finally, it depends on the research question which method is more suitable (Stracke, 2004, p. 35). For the present study, no concept prompts were made except of those within the task. But some relations were offered in an open pool format (Table 18.1).

Thus, every test person had the chance to create his or her knowledge map with individual associations. After collecting the knowledge maps created with paper-pencil method, they were transferred into the software package CmapTools. CmapTools is an open source program developed by IHMC.[5]

2.2.2 Sample

The survey concerns 48 first grade students (Bachelor of Science in Vocational Education and Training) at the Johannes Gutenberg University in Mainz, Germany. The test people were between 19 and 36 years old (while age related, the 36-year-old test person embodies an outlier). Related to the gender, 17 of the test people were male and 31 were female. Only half of the students ($n = 24$) finished a vocational training, 23 of them in the field of business management. This distinction was important to know, as different knowledge structures in the field of money management were expected from people with a business management graduation compared to people without.

[5] Florida Institute for human and machine cognition, http://cmap.ihmc.us/conceptmap.html

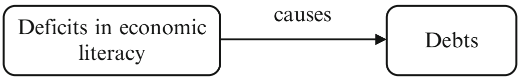

Fig. 18.1 Example for a proposition (concept-relation-concept)

2.2.3 Implementation of Data Analysis

The methodology of analyzing the 48 individual knowledge maps follows a two-stage approach. First, there is a categorization of the individual concepts into a shared set of subject matter phrases. This coding process is well known as "content analysis procedure" (Mayring, 1995). The categorization is necessary to create comparability. Therefore, every knowledge map was differentiated in its propositions (Fig. 18.1).

Afterwards, similar propositions were summarized in a global category. This process is oriented in Mayring's qualitative content analysis (1995). The aim is to reduce the current data by preserving the original meaning. In addition, Fürstenau and Trojahner (2005) describe methodological characteristics for the analysis of knowledge maps. A critical issue in this respect is the choice of a level of resolution which on the one hand allows for depicting communalities and on the other for individual emphases. The categorization process is executed on the four-eye principle.

2.2.4 Evaluation Methods for Knowledge Maps

To evaluate knowledge maps, two methods can be used: a qualitative and a quantitative analysis. The choice for one method depends on the quality of knowledge that should be ascertained. To comprehend structural knowledge (in our study: economical structural knowledge), an analysis of isolated concepts and relations is not target aimed. Therefore, it is important to get information about the structure of a map. This information can be obtained by analyzing the networks quantitatively, which means structurewise. Therefore, it is legitimate to go back to indices of the graph theory (Weber & Schumann, 2000, p. 173). Networks will therefore be defined as "subscripted, directed graphs with labeled edges" (Bonato, 1990, p. 7). The individual knowledge structures and therefore the structure of the knowledge maps differ in the number of nodes (concepts) and the amount of edges (relations). To analyze the maps quantitatively, Susanne Weber (1994, p. 29) suggests the following indicators and indices (Table 18.2):

Susanne Weber's indices go mainly back to the indices used by Bonato to describe mathematical graphs. But there is one important assumption that needs to be considered: Weber (1994, p. 29) assumes that knowledge networks allegorize an externalization of underlying individual internal structural representations. Therefore, these indices cannot be used in this study because the modal network is an "artificial construct" that does not represent an individual knowledge structure (Fürstenau & Trojahner, 2005, p. 198). Therefore, it does not make much sense to use these indicators to analyze and compare the referential networks.

Table 18.2 Quantitative indices by Weber (referring to Weber, 1994, p. 72)

Dimension	Indicator	Index
Volume	Size	Number of prepositions
Structure	Degree of jaggedness	Number of connecting components
	Connectivity	Density
	Centrality	Diameter
		Median and Average value
	Main and side effects	Status index by Hoede

For detailed information to each dimension, indicators, and indices, see Weber (1994) and Melke (2002)

A quantitative measure to evaluate referential networks is the concordance to the gathered individual networks. It is a specific measure for referential networks because it shows how good the individual networks of the study participants will be represented in the referential network. It states the percentage of propositions from all individual networks which are also represented in the referential network (Fürstenau & Trojahner, 2005, p. 198). In the present study the concordance is therefore the only useful indicator to evaluate the referential networks as it is a goal of the study to find a representative reference network in the field of private financial processes.

As an alternative to a quantitative, the qualitative analysis is often found in literature. It is useful to evaluate the knowledge basis of each person in detail. But as the modal network is a theoretical created network (and not a network built by a test person), it is not useful to analyze it qualitatively. As a partly content-based analysis, it has been checked if all propositions in the referential networks stated true connections between the concepts.

2.2.5 Results

It is the aim of the content analysis to reduce the large number of concepts and relations to make the networks more comparable. In this process it is important to obtain the original statement. In a first step, the categorial content analysis, the propositions had been dispersed into its concepts and the relation. All concepts and relations had then been analyzed separately. The primal amount of 411 concepts and 60 relations was reduced to 247 concepts and 40 relations. In a second step, the structural content analysis, the entire categorized propositions had been used. Because of the categorial analysis, the networks contained double or reflective propositions. On the basis of the assumption that all propositions only exist once in the cognitive structure of a person, propositions that occurred more often in a network had been dropped. From 2010 propositions only 1871 remain after the structural content analysis. In average each network consisted of 39 propositions (mean = 38.98). In addition, a computation of the congruencies between the 48 categorized maps has been done by means of the tool "Netzwerkzeug" (Oldenbürger, 2007). Modal and prototypical networks have been generated and analyzed.

The *modal network*[6] contains the most common propositions. The amount of propositions within the modal knowledge map refers to the average amount of propositions beyond every network (Fürstenau & Trojahner, 2005, p. 197). The idea of modal networks as representation of social perceptions cannot be assumed doubtless. Fürstenau and Trojahner (2005, p. 198) criticize a modal network as an "artificial construct," because it is build from single propositions and does not exist as a network which represents the knowledge structure of a test person. Therefore, some inexplicable propositions can emerge. The modal network of the previous study is shown in Fig. 18.2. It consists of 34 propositions, which is the average of all networks (the individual maps varied between 18 and 120 propositions). The calculated concordance to the collected students' networks comes to 8.7 %, which is a very low value, considering that it reflects the validity of the network.

The *prototypical network* supposes a pair comparison of the gathered networks. It is therefore a "real" network that has been created by one of the test people. It is the network that is closest to all others concerning the content and structure (Fürstenau & Trojahner, 2005, p. 198–200).[7] The prototypical network in the current study contains 47 propositions. In terms of scope and size, the prototypical network seems to be more sophisticated. However, the concordance to the gathered networks comes to 1 %. That result shows that the prototypical network does hardly reflect the other networks. As already explained, the students were free in choosing the concepts, and they could define their own relations. This might be one reason for the diversity of the networks and therefore for the low concordance (Fig. 18.3).

The low concordance in both referential networks indicates that the test people have very individual perceptions concerning the topic of private money management. Additionally, a more detailed analysis has been implemented. As half of the test people already finished a vocational training, the modal and prototypical networks of this group have been compared to the networks of the group of students without a vocational training. 23 (out of 24) students finished a vocational training in the field of business management. During their training they learned about economic coherences. Therefore, they might have a different perception about individual financial processes. The results of the comparison between these two groups are shown in Table 18.3.

The concordance of the modal network of the group with a vocational training is a bit higher than the concordance of the reference group. This shows that the networks of the students with a vocational training are a bit more homogeneous than the networks within the group without training. But even 11.57 % is still a low concordance, which shows that even in this group the cognitive structures seem to be quite different regarding this topic.

[6] The term "modal network" is used as synonym for "modal knowledge map."

[7] A detailed description on how to reckon a prototypical network can be checked at Fürstenau and Trojahner (2005, p. 198–200).

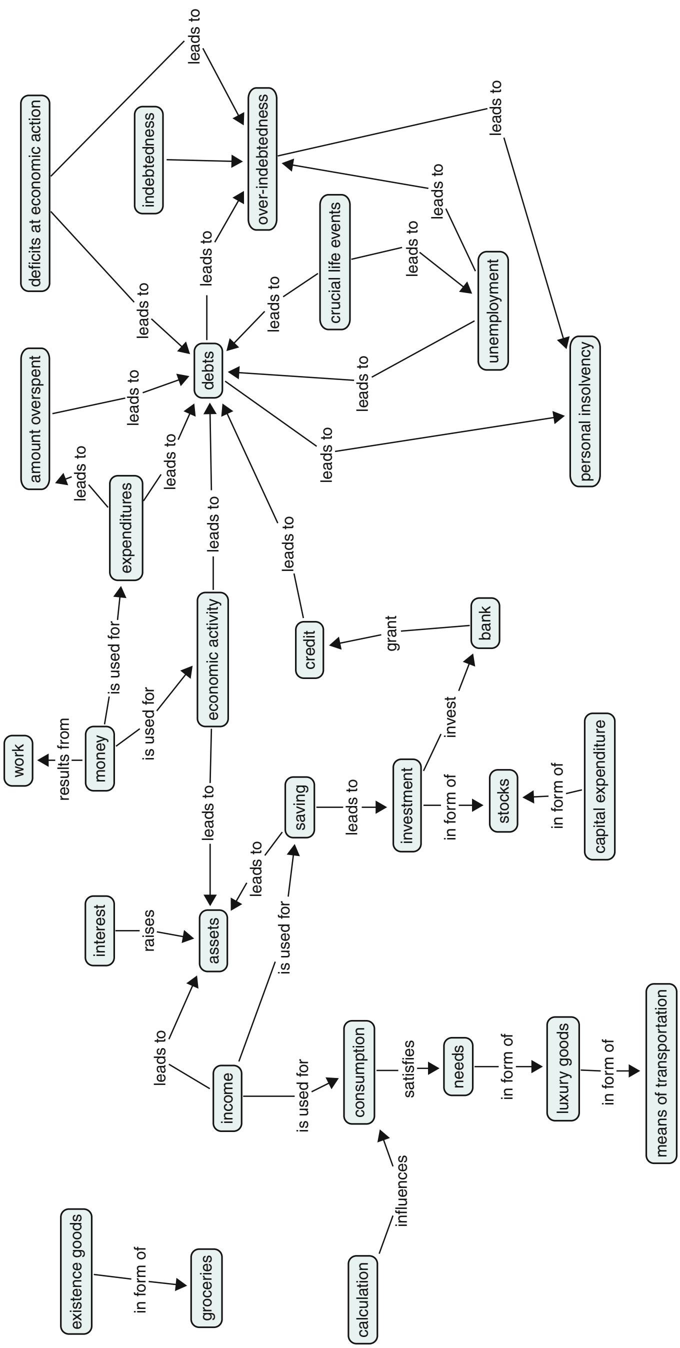

Fig. 18.2 Modal network

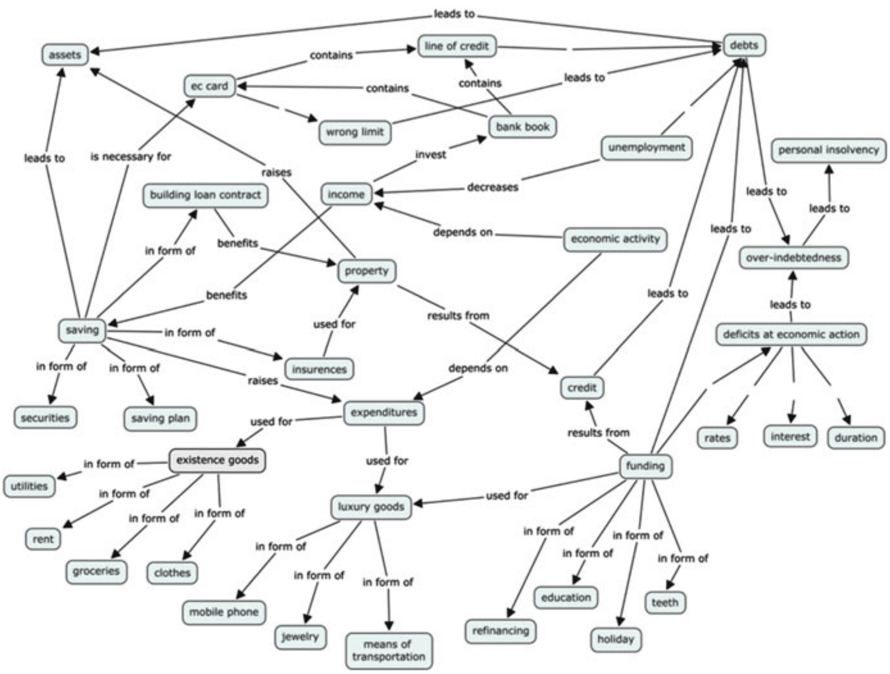

Fig. 18.3 Prototypical network

Table 18.3 Concordances of the referential networks of the group of students with vocational training compared to the group without a vocational training

	Modal network	Prototypical network
Students with vocational training	11.57 %	1.21 %
Students without vocational training	7.95 %	1.41 %

3 Post hoc Analysis

In order to validate the initial analysis, we used an automated analysis tool for a post hoc analysis. The post hoc analysis was used to investigate two research questions: (1) Are there differences between the two experimental groups (VT = vocational training group; NT = no vocational training group) and (2) are there intraindividual differences within the two experimental groups?

The underlying assumption of AKOVIA (Automated Knowledge Visualization and Assessment; Ifenthaler & Pirnay-Dummer, 2013) is that cognitive structure can be externalized as a graph (Ifenthaler, 2010). A graph consists of a set of vertices whose relationships are represented by a set of edges (Tittmann, 2010). Various measures from graph theory have been successfully applied in previous studies in order to analyze externalized cognitive structure and their development over time (e.g., Bonato, 1990; Ifenthaler, Masduki, & Seel, 2011; Jonassen & Cho, 2008).

Table 18.4 Description of the seven AKOVIA measures

Measure [abbreviation] and type	Short description
Surface matching [SFM] *Structural indicator*	The surface matching compares the number of vertices within two graphs. It is a simple and easy way to calculate values for surface complexity
Graphical matching [GRM] *Structural indicator*	The graphical matching compares the diameters of the spanning trees of the graphs, which is an indicator for the range of conceptual knowledge. It corresponds to structural matching as it is also a measure for structural complexity only
Structural matching [STM] *Structural indicator*	The structural matching compares the complete structures of two graphs without regard to their content. This measure is necessary for all hypotheses that make assumptions about general features of structure (e.g., assumptions which state that expert knowledge is structured differently from novice knowledge)
Gamma matching [GAM] *Structural indicator*	The gamma or density of vertices describes the quotient of terms per vertex within a graph. Since both graphs that connect every term with each other term (everything with everything) and graphs that only connect pairs of terms can be considered weak models, a medium density is expected for most good working models
Concept matching [CCM] *Semantic indicator*	Concept matching compares the sets of concepts within a graph to determine the use of terms. This measure is especially important for different groups that operate in the same domain (e.g., use the same textbook). It determines differences in language use between the models
Propositional matching [PPM] *Semantic indicator*	The propositional matching value compares only fully identical propositions between two graphs. It is a good measure for quantifying semantic similarity between two graphs
Balanced semantic matching [BSM] *Semantic indicator*	The balanced propositional matching is the quotient of propositional matching and concept matching. In specific cases (e.g., when focusing on complex causal relationships), balanced propositional matching could be preferred over propositional matching

AKOVIA uses specific automated comparison algorithms to calculate similarities between a given set of properties (Ifenthaler, 2010). The resulting similarity index s results in a measure of $0 \le s \le 1$, where $s = 0$ is complete exclusion and $s = 1$ complete identify. Table 18.4 shows the seven measures of AKOVIA, which include four structural and three semantic measures (Ifenthaler, 2010; Ifenthaler & Pirnay-Dummer, 2013; Pirnay-Dummer & Ifenthaler, 2010).

The analytic strategy included three steps: (1) transformation from raw data into list from, (2) construction of a model net which was used as a reference model for the AKOVIA comparison algorithm, and (3) AKOVIA similarity comparison.

In order to answer the first research question of the post hoc analysis, we computed seven independent t-tests for each of the AKOVIA similarity measures. Results showed no significant differences between the two experimental groups for the seven AKOVIA similarity measures, SFM, $t(46) = 1.31$, $p = 0.195$; GRM, $t(46) = 1.33$, $p = 0.895$; STM, $t(46) = 0.86$, $p = 0.394$; GAM, $t(46) = 0.93$, $p = 0.358$; CCM, $t(46) = 1.31$, $p = 0.195$; PPM, $t(46) = 0.31$, $p = 0.756$; and BSM, $t(46) = 0.842$, $p = 0.404$ (see Fig. 18.4).

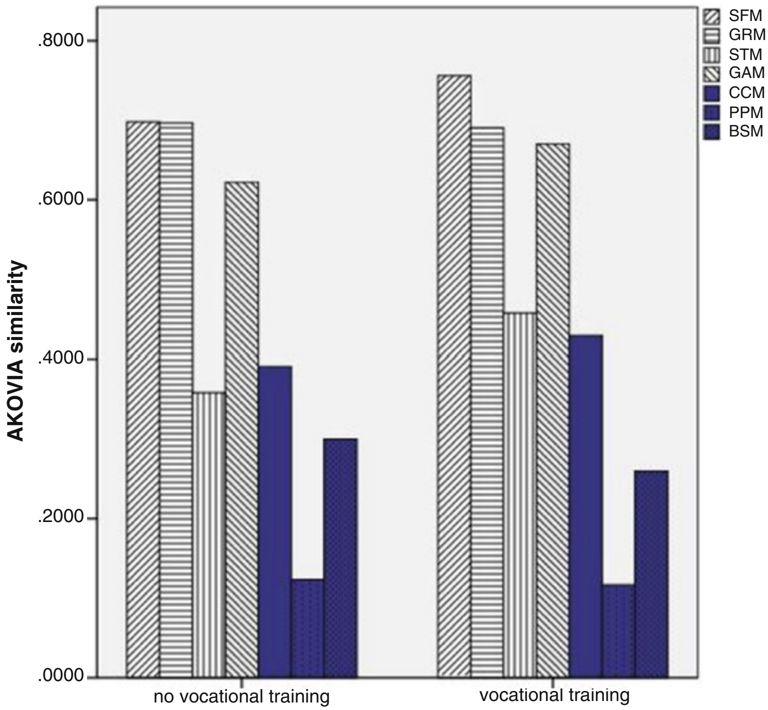

Fig. 18.4 AKOVIA results for the two experimental groups

In order to answer the second research question of the post hoc analysis, we computed 14 one-sample Kolmogorov-Smirnov tests for each of the AKOVIA similarity measures and both experimental groups. Table 18.5 shows the results of the intraindividual differences separated for the two experimental groups.

The only significant intraindividual difference was found for the STM measure. Accordingly, the participants in both experimental groups structured their knowledge maps very different. However, the broadness (SFM), complexity (GRM), connectedness (GAM), and semantic correctness (CCM, PPM, BSM) of the knowledge maps did not significantly differ among the participants.

4 Discussion

Altogether, the modal network and the prototypical network have only marginal concordance test persons' networks. While the modal network represents the test persons' knowledge maps at 9 %, the prototypical network reaches only 1 % of similarity to every single knowledge map which means that they are not represented through the prototypical network. In literature, a representation factor of 20 % is declared as a minor degree of representation (Weber, 1994, p. 129). The common value is therefore not acceptable to rate the modal networks as well as the prototypical

Table 18.5 Within group differences of AKOVIA similarity measures

AKOVIA measure	Exp. group	Mean	SD	Min	Max	KS-Z	p
SFM	VT	0.76	0.15	0.38	0.97	0.54	0.94
	NT	0.70	0.16	0.24	0.94	0.96	0.32
GRM	VT	0.69	0.16	0.36	0.93	0.91	0.38
	NT	0.70	0.15	0.36	0.93	0.88	0.42
STM	VT	0.46	0.40	0.00	0.86	1.53	0.02
	NT	0.36	0.41	0.00	0.92	1.73	0.01
GAM	VT	0.67	0.19	0.26	0.99	0.49	0.97
	NT	0.62	0.17	0.29	0.96	0.46	0.98
CCM	VT	0.43	0.08	0.26	0.60	0.59	0.88
	NT	0.39	0.12	0.12	0.65	0.76	0.62
PPM	VT	0.12	0.08	0.00	0.27	0.52	0.95
	NT	0.12	0.08	0.00	0.29	0.55	0.92
BSM	VT	0.26	0.17	0.00	0.60	0.42	0.99
	NT	0.30	0.16	0.00	0.65	0.57	0.91

Note. VT = vocational training group; NT = no vocational training group

network as referential structures. The deduction of a referential structure does not seem to be meaningful regarding these results. There are several reasons towards this finding. First, the task can be worded too widely, which means focused and congruent patterns can just be identified hardly. Novak and Cañas (2006, p. 1) recommend tight questions with appropriate impulses. Furthermore, the tabooing of private financial issues can lead to a lack of shared cognitions. Third, the methodology of categorizing can cause the mentioned deficits. The question is whether to strengthen the categorization through higher degrees of abstraction. But surveys can show that a higher degree of abstraction is only promising if the initial value is 20 % minimum (Weymar, 1986, p. 137). All these arguments can explain the quantitative lack of concordance between the collected networks. Regarding the individual maps on a semantic scheme leads to the conclusion that every test person could identify two main dimensions of money management at last: consumption and asset accumulation. Anyway, the test persons' networks towards private money management can be declared as idiosyncratic which indicates a lack of formal and systematic development of financial competence. The hypothesis of a low level of concordance between the individual knowledge networks is supported at the statistical level.

The post hoc analysis with the automated AKOVIA analysis confirmed the initial analysis of the knowledge representations on an inferential statistics level. The two experimental groups did not differ with regard to their overall understanding of the subject domain.

To sum up, formal education towards financial subjects does not seem to exercise any significant influence on individuals' structural knowledge in this domain. The finding, however, has to be discussed in reference to the methodology applied. This discussion will include issues of validity and reliability of knowledge mapping for depicting shared cognitions.

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Chapter 19
Predispositions to Concept Mapping: Case Studies of Four Disciplines in Higher Education

Gregory MacKinnon, Rohan Bailey, Patricia Livingston, Vernon L. Provencal, and Jon Saklofske

Abstract This chapter investigates the response of four teaching academics in higher education to the use of electronic concept mapping. As such, it would be considered primarily a phenomenological study rooted in qualitative analysis. In particular, the chapter will analyze four independent projects where the instructor used electronic concept mapping for the first time. The academics first undertook these projects beginning in 2010. Three academics teach in North American universities while the last works in a Jamaican university. These projects include (1) use of electronic concept mapping to design anesthesiology curriculum in a medical school, (2) research on the use of virtual worlds in teaching undergraduate English literature, (3) the use of two-dimensional concept mapping in teaching undergraduate Greek mythology, and (4) using concept maps in a Jamaican graduate course in

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architecture education The analysis and synthesis of these findings will provide an introspective that sensitizes potential users to the nuances of the technology and how important it is to consider first the inherent pedagogical framework.

Keywords Concept map • Higher education • Technology integration

1 Introduction

The "net generation" of students (Dobbins, 2005) has put tremendous pressure on faculty in higher education (Hartman, Moskal, & Dziuban, 2005). This is due in part, to the pedagogical challenge, that instructors responsibly prepare students for an increasingly technological world.

In a recent report on technological horizons, the authors suggest that "Digital media literacy continues its rise in importance as a key skill in every discipline and profession." (Johnson, Adams, & Cummins, 2012, p 6). Dede (2007) cited Jenkins, Clinton, Purushotma, Robison, and Weigel (2006), who have identified literacies associated with student engaging in new types of media as follows:

- "Play, the capacity to experiment with one's surroundings as a form of problem solving;
- Performance, the ability to adopt alternative identities for the purpose of improvisation and discovery;
- Simulation, the ability to interpret and construct dynamic models of real-world processes;
- Appropriation, the ability to meaningfully sample and remix media content;
- Multitasking, the ability to scan ones environment and shift focus as needed to salient details;
- Distributed cognition, the ability to interact meaningfully with tools that expand mental capacities;
- Collective intelligence, the ability to pool knowledge and compare notes with others toward a common goal;
- Judgment, the ability to evaluate the reliability and credibility of different information sources;
- Transmedia navigation, the ability to follow the flow of stories and information across multiple modalities;
- Networking, the ability to search for, synthesize, and disseminate information; and
- Negotiation, the ability to travel across diverse communities, discerning and respecting multiple perspectives, and grasping and following alternative norms." (p. 23)

While these may be new literacies, they by no means diminish the importance of preparing students with skills related to more traditional notions of critical thinking, metacognition, and effective communication. With the technology at our disposal today, it is an arguably manageable while sophisticated process to respond to all of these literacies as well as quality curriculum design (Wiles, 2009). This can be accomplished using approaches that capitalize on the established benefits of digital knowledge maps (Novak & Gowin, 1984; Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). This chapter focuses on the reaction of professional educators to the potential for concept maps (a specific digital knowledge map) in pedagogical practice.

2 The Power of Graphic Organizers

Ausubel (1960) arguably set the stage for investigating the potential for graphic organizers to assist in what he called "meaningful learning." Dye (2000) had proposed that graphic organizers are founded on a schema theory of organizing information (Winn & Snider, 1996). Slavin (1991) further suggested that in accommodating new knowledge, the learner encodes and stores organized retrievable information in a "scaffolded hierarchy." Paivio (1986) posits a "dual coding" theory in which information is processed via two distinct systems: nonverbal imagery and language. While these systems operate independently, they also interact, especially in the context of digital knowledge maps. It is widely held that dual coded information is easier to retrieve and retain because of the availability of two mental representations, i.e., verbal and visual (Marzano, Pickering, & Pollock, 2001; Paivio, 1986; Wills, 2005).

2.1 Three Approaches from the Literature to Digital Knowledge Maps in Education

In terms of using knowledge mapping in education, the work of Scardamalia et al. (1989) is notable. They created "Computer Supported Intentional Learning Environments" (CSILE) which were essentially user-generated graphical representations (Fig. 19.1) of knowledge sharing that demonstrated multiple perspectives, multiple literacies, and teamwork in constructing knowledge. This graphical network of shared learning, now referred to as "knowledge forum" (see http://www.knowledgeforum.com/), has been optimized in a plethora of settings and boasts the knowledge building attributes of real ideas, authentic problems, improvable ideas, idea diversity, epistemic agency, collective responsibility, democratized knowledge, symmetric and pervasive knowledge advancement, constructive use of authoritative sources, knowledge building discourse, and transformative assessment (Scardamalia, 2004; Scardamalia & Bereiter, 2006). This form of digital knowledge mapping promotes the potential of cooperative communities of knowledge construction.

Integrating technology with teaching represents a sophisticated pedagogical consideration. Mishra and Koehler (2006) have contributed a knowledge map in the form of a Venn diagram (see redrawn Fig. 19.2). Their technology, pedagogical, and content knowledge model (TPACK) and the imparted knowledge sector distinctions have demonstrated how a knowledge map can promote "thinking about thinking" (metacognition), a process that greatly benefits both educators and curriculum planners.

A concept map is a hierarchal graphic organizer that places the most inclusive idea at the top and the most specific concepts at the bottom. Boxes containing

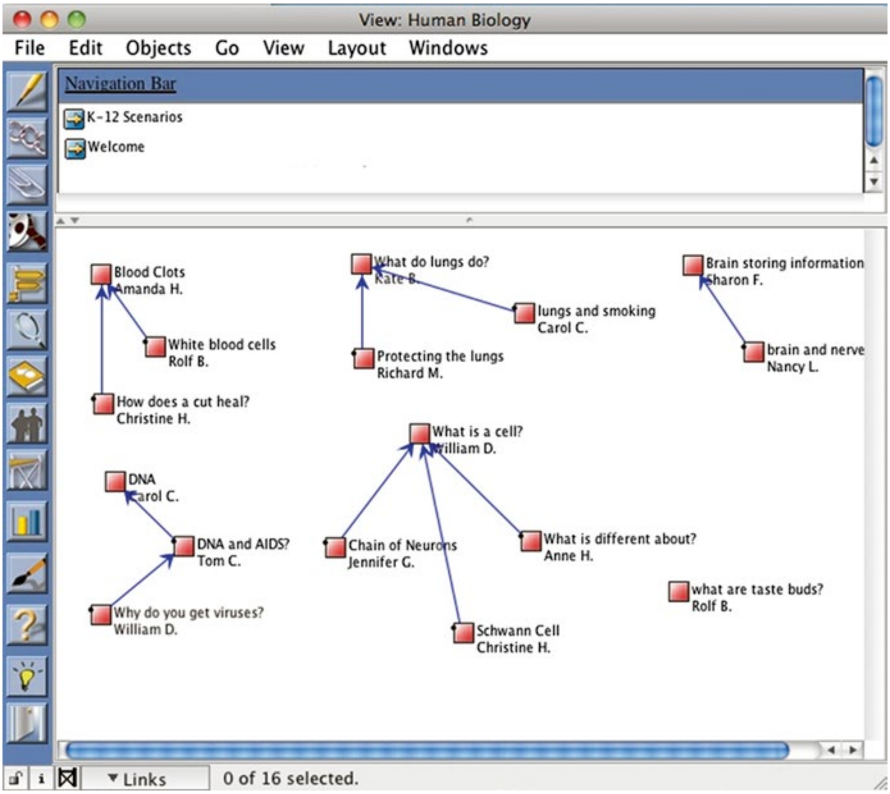

Fig. 19.1 Knowledge Forum: knowledge building using digital maps

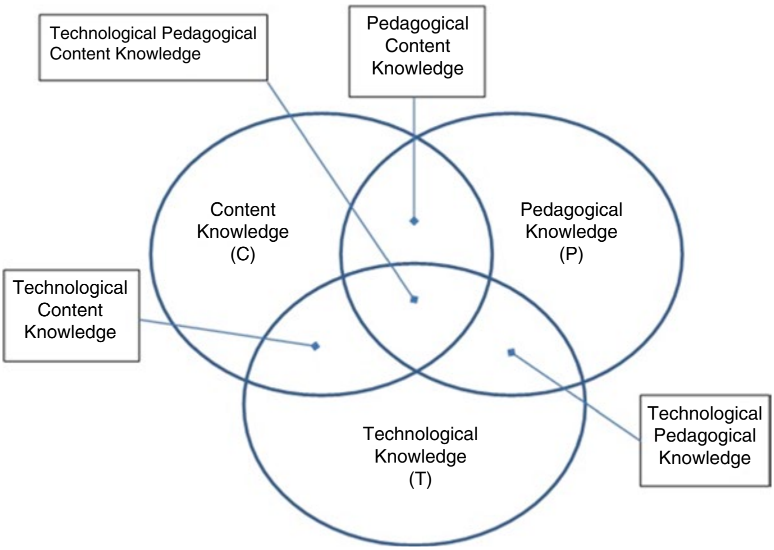

Fig. 19.2 Venn diagram as digital knowledge map

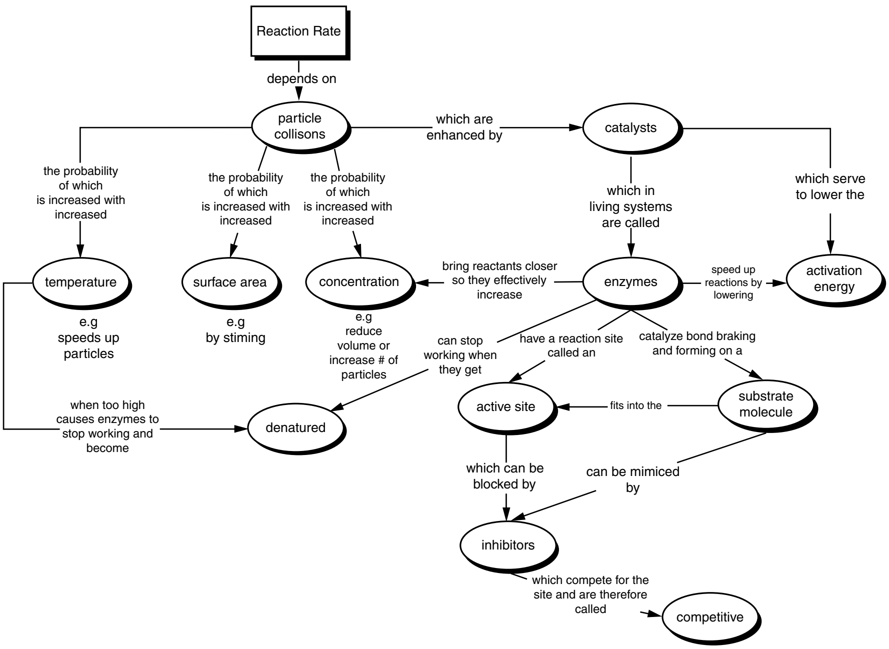

Fig. 19.3 A chemistry concept map

concepts are linked by lines emanating downward or across that in turn are labeled with information-rich propositional phrases. Concept mapping has its roots (Novak & Gowin, 1984) in the monitoring of student's conceptual change following a teacher's classroom intervention such as a new pedagogical approach. With the advent of electronic mapping programs (e.g., Inspiration®, CMap®), concept maps can be produced digitally, which allows for limitless adaptations and reiterations.

Concept mapping (Fig. 19.3) has been used in a host of contexts ranging from curriculum design to teachers and students negotiating maps (MacKinnon & Keppell, 2005). The formulation of concept maps constitutes an excellent example of the process of knowledge accommodation, a term coined by Piaget (1977). As the author(s) creates their digital knowledge map, they are forced to consider their newfound knowledge in the context of their prior understandings; as such, building the concept map is a decidedly constructivist exercise (Brooks & Brooks, 1993).

3 Four Examples of Concept Map Applications in Higher Education

While concept mapping seems like a generically useful digital knowledge map, it has become evident through research of numerous educational applications (Åhlberg, 2004; Al-Kunifed & Wandersee, 1990; Basque & Lavoie, 2006; Chularut & DeBacker, 2004; MacKinnon & Provencal, 2009; MacKinnon & Saklofske, 2011) that not all users adapt to "mind-mapping" in this way. This chapter uses four vignettes of map usage to enlist feedback from teaching academics in distinctly varied content areas. The chapter deconstructs the core themes and attempts to triangulate the wide range of perspectives in light of literature studies.

4 Methodology

Instructors in anesthesiology, English literature, Greek classics, and architecture were each asked to respond to a series of questions regarding their specific experiences with concept mapping. The core aim of the research was to identify the nature of interaction between a specific technology and the pedagogical aims of the instructors using that technology. More specifically, the research was undertaken to determine the factors that impact how the inherent teaching philosophies and practices of a range of instructors could impact how they react to the potential of a new technological teaching and learning tool.

The sample of instructors was chosen based on the breadth of their subject area expertise; the range of experiences across undergraduate, graduate, and professional education; their distribution geographically; and finally their previous professional interactions with the first author.

The foundational questions posed to each instructor were as follows:

1. What is your pedagogical disposition? (e.g., philosophy, teaching and learning strategies, student engagement, learning assessment)
2. What was your initial reaction to concept mapping?
3. Describe your disposition to concept mapping after the concept mapping experience.

Over a period of 2 years (from 2010 onward), responses were received from individual academics via a variety of formats that included formal transcribed interviews, ongoing informal conversations by telephone and Skype (with accompanying field notes), and submitted documents via email correspondence.

The empirical materials (in the form of text-based accounts) were collected from and corroborated with each instructor to remove ambiguity of intent. The entire group (all instructors' feedback) of documents were coded in an iterative approach (Huberman & Miles, 2002) in an effort to identify common themes. The concomitant analysis and conclusions were then shared with individual instructors in a member check session (Guba & Lincoln, 1989).

Each context is described below along with a summary of their responses followed by a cross comparison of emergent themes.

4.1 Concept Mapping Curriculum in Anesthesiology

A practicing anesthesiologist (hereafter PA) was asked about her teaching philosophy to offer a glimpse of the underpinnings that may impact her use of concept maps.

This PA teaches at the graduate university level in both North American and African contexts. Fundamental to her teaching is making clear expectations and goal setting, assessment of prior knowledge, advanced reading requirements, linking past topics to new ones, moving towards interactive sessions, case-based teaching, and class summaries. Assessment of learning in PA classes typically involves testing of conceptual understanding and process knowledge (regarding anesthesiology practice) in both written and practical ways.

With regard to personal learning styles (Gardner, 1993), the PA suggested the following:

> I am definitely a visual-spatial-tactile learner. Images help enormously. I also learn by looking at a problem from many different ways. It works well to read about a topic and apply it to a case. Visual organizers and charts are very helpful. Looking at the big picture is important.

To provide context, the PA had been introduced to concept mapping (by the first author) in a graduate level education course. In this course, she saw examples of how instructors could plan their curriculum using mapping and furthermore share this planning with their own course students as a precursor and advanced organizer of the curriculum their students were about to undertake. The concept mapping example used in this graduate course was the circulatory system (see Fig. 19.4).

The first reaction of PA to concept mapping was to appreciate the organization it could lend to a vast amount of knowledge as a concrete way of showing the interconnectedness of curriculum. In the context of teaching anesthesiology, this initial recognition of the potential for concept mapping however was balanced with a certain concern that the "processes" of anesthesiology would be difficult to articulate.

This introduction to concept mapping was followed up by PA in the form of a leadership role in reconsidering the entire anesthesiology curriculum in a medical school residency program. Her experience of trying to employ concept mapping is captured in the following comments:

> The idea of a curriculum map or concept map for the curriculum might work with what we call our didactic curriculum…however anesthesia is highly experiential, based on the cases you happen to encounter. Maybe this can all be captured in a concept map but it seems rather overwhelming.
>
> In the OR [operating room] a lot of what happens is pattern recognition. You need to be around for a while to begin to catch on. It is about training your sense perceptions to be in tune with what is happening in the total environment so you can maintain a safe situation for the patient. It seems to me the concept mapping is a better fit for the didactic part where you have a program such as reviewing all the body systems.

It seems clear from this feedback that the PA sees concept mapping as more of a listing of curriculum topics, and while the topics seem manageable in a hierarchy, the host of process skills (including situated learning around problem solving in the OR) is much more difficult to accommodate in a digital knowledge map. Her finding (PA) that the content can nonetheless be easily mapped is not new. Previous studies in undergraduate physics education showed (MacKinnon & Williams, 2006) that students and instructors alike found the mapping of content knowledge to be quite facile. This was attributed to experiences with the preponderance of curriculum organizational diagrams in many science textbooks and the hierarchal nature of science.

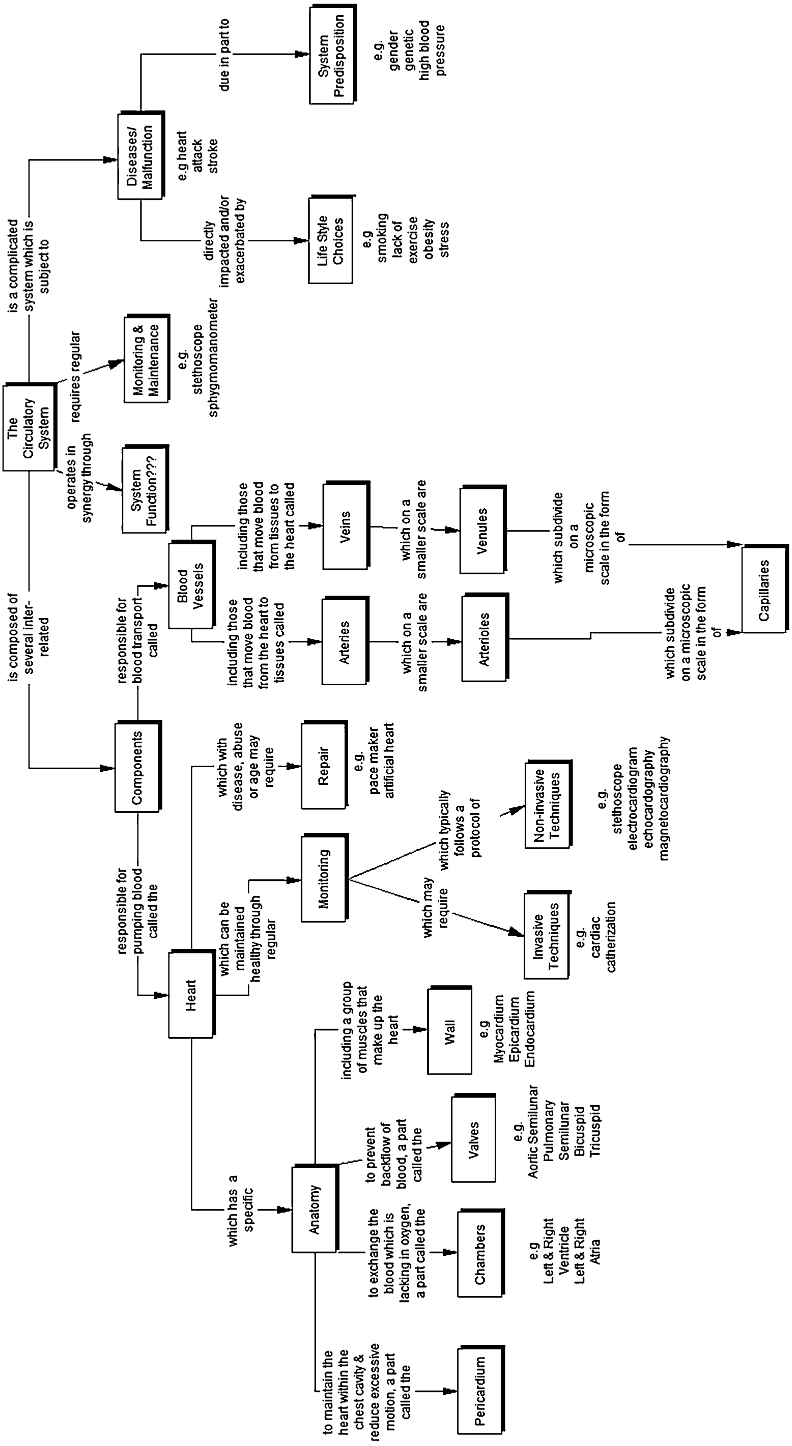

Fig. 19.4 A circulatory system concept map

PA was not prepared to suggest that concept mapping was not suitable for anesthesiology but rather that she had limited practice with the application of concept mapping. Some measure of success (Helfgott, Brewer, & Novak, 2010) has been achieved using concept mapping to represent "medical decision analysis" and "medical knowledge modeling" both of which would include the practical nature of being a physician.

4.2 Concept Mapping as Assessment Tool in English Literature

An undergraduate English literature professor in a small Canadian liberal arts university (hereafter ELP) was asked to explain his teaching philosophy to which he responded the following:

> Teaching is a mentored exchange whereby I engage my students with ideas and let them explore the parameters and boundaries of those ideas while acting as a rudder to keep them moving toward a collaborative understanding of concepts and contexts. To this end, my engagement with students in the classroom involves a combination of initial "stage setting," whereby the parameters and themes related to a particular reading are introduced, followed by a series of open-ended discussion questions that engage the community of students to explore paths of understanding and to correlate larger frames of reference around that reading. Rather than presenting and condensing information directly to the students and expecting them to regurgitate such detail, I work with them through a process of understanding that they can take ownership of. I am careful to discuss my expectations of students early at the beginning of the course, which include active participation in the classroom community, adopting strategies for intrinsic motivation, the courage to engage fully with course material and its resonant interpretations, and to cultivate a respect for alternative and contradictory perspectives.

This particular instructor assesses students via traditional essay writing, reader responses, journal entries, oral presentations, group projects, and class participation. The area of specialty of ELP is Romantic period literature, so it was no surprise that he identified learning style strengths in linguistics, music, interpersonal, and intrapersonal modes. He also documented his strength in logical-mathematical ways of learning which is manifested in his interest in technology and teaching.

He had little experience with graphic organizers during his formal education and shared the following comment "there was little opportunity to make use of graphic organizers to present, understand or organize information. Perhaps this is because literary scholarship privileges the word over the image, and perhaps it is because my education happened at a time before the widespread exposure to multiple-media technologies."

The ELP was introduced to concept mapping in a research project involving classroom technologies (MacKinnon & Saklofske, 2011). Specifically, concept mapping was being used to assess the change in conceptual understanding of ELP's students (Fig. 19.5) following a classroom intervention. In particular, ELP had designed a virtual world where students experienced the "historical context"

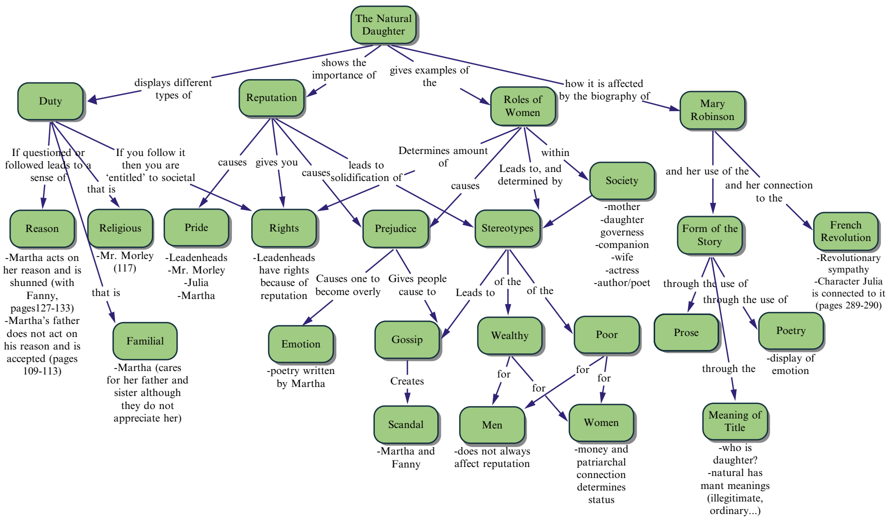

Fig. 19.5 Student-generated post-virtual world concept map of the Natural Daughter

of the novel "The Natural Daughter" by Mary Robinson. Students read the novel and interacted within the virtual world. In viewing students' pre- and post-concept maps (with respect to the virtual world experience), ELP was able to ascertain the knowledge transfer as a direct result of the virtual world. An important outcome of the study was the understanding that classroom discussions that supplement the technology use were fundamental to the impact of the virtual world.

As a preface to pre- and post-student concept mapping, two exercises were undertaken to familiarize the student and instructor with the process of mapping. In the first instance, a group of concepts component to a children's story were provided, the task being to organize them in a concept map. This was followed with a class discussion of the positioning and logical rationale for the map concepts. The second exercise involved students and instructor reading the sonnet "On Being Cautioned…" by Charlotte Smith. They were told to sequester the main themes and to draw their own concept map based on the identified concepts. ELP shared his map with the students as a center piece for discussion of the sonnet. During the phase of the research when students were drawing pre- and post-virtual world concept maps, the instructor also drew his own map for the novel "Natural Daughter." This was used as a "reference map" to compare structural features with the students' concept maps, a technique that has gained in popularity (Kinchin, Hay, & Adams, 2000; Lopez, 2008; Silva, Romano, & Rogerio, 2010).

The initial reaction of ELP to concept mapping was from a position of skepticism. Given his content background in English literature, it was an uncomfortable paradigm. "While I recognized intersections between its [concept mapping] processes and some of the logical processes by which I arrange and communicate my literary scholarship and output, it appeared to impose artificial and hierarchical patterns on information." Despite ELP's initial reticence to the approach, he communicated a positive attitude and understanding of the potential value of organizing ideas in a logical format not entirely unlike his experiences with visual outlines as a student. Nonetheless he suggested "This optimism did little to deflate the difficulty that I experienced while initially using this tool to represent my understanding and teaching structures, and this difficulty was largely due to a disparity between my conception of the specific strategies and methods used to understand literary material, and the specific ordering processes that concept mapping imposed on this material."

As alluded to above, ELP later constructed a concept map of the novel "Natural Daughter" and had this insight to offer:

> Once I became accustomed to the types of content and connections that the concept map required, I created an extensive graphic that was more detailed than (the author) had initially expected, but which demonstrated the depth and density of concepts that I was extracting from the novel during my classroom discussions. While this extensive representation pointed to the complexity of integrated ideas and themes that connected the book to the rest of the course content, the concept map—while quite large—revealed an overall order to these concepts that I had not fully understood or realized prior to the completion of the map.

The value of the map to his teaching became further evident when ELP posited that

> This visualization, thus organized was extremely illuminating, both to my students' understanding of my intentions and directions related to the reading, and to my own understanding of the kinds of opportunities presented by following specific paths and tracing particular interconnections through the mapped concepts. The map has since become a key to developing new pedagogical strategies related to that particular reading.

The impact of the concept mapping on ELP's approaches to teaching has been measurable. An interesting artifact of the research came about as a result of ELP showing his concept map to his students. They found the sheer enormity of the map extremely intimidating compared to their own maps, however, said ELP:

> The clarification that the map provided to the students about my interests and intentions related to the novel's content generated feedback that was critical about a pedagogical approach that did not include such concept maps. In other words, the students saw the map as a clarification and crystallization of concepts that they had been working through, but which had not been structured in this relative fashion.

In the thinking about his teaching philosophy, ELP concluded that constructing the map with the students would provide a sense of ownership in the material while capitalizing on the recognized organizational benefits much less the clarity of the learning objectives. Another approach that ELP considered follows:

> The concept map would be a useful curriculum planning tool for organizing and modifying course content, and I would have no problems providing students with a simple, less-detailed, overarching summary map of the course's major themes during the first week of class. The map could serve as a reference point that students could return to throughout the term and modify or add detail to as they gathered new examples and information. In no way would this predispose me to following a mapped curriculum through the course, as I see this as a tool for streamlining the process of course refinement and evolution.

4.3 Two-Dimensional Concept Mapping in Greek Classics

An instructor's ideas about the teaching process can necessarily shape his/her attitude towards concept mapping. To that end, an undergraduate university classics professor in a North American context (hereafter CP) was posed the aforementioned questions regarding his teaching philosophy to which he responded:

> At the university level, I was exposed to the Socratic method of being asked to examine one's own assumptions about something as a necessary prerequisite to learning about it. For example, if we are to study the Greek gods, we should begin by asking what our assumptions are about gods and the myths by which the Greeks learned about their gods. It is commonly assumed that myths are just stories in the sense of folklore, and that a god—or 'God'—is a matter of private belief. If so, then we should understand that that is nearly the opposite of what the Greeks believed. They believed gods were simply there in a sense, as we might believe gravity or microwaves or binary code are there, not as a matter of private belief but of common knowledge.
>
> Socratic learning presupposes the intuitive ability of the mind to discover (or recover) from within its own nature a knowledge of external reality—all knowledge is self-knowledge in that sense.

When asked about predisposition to multiple learning styles, CP suggested that his own personal strengths were in linguistic, musical, and bodily-kinesthetic modes of learning. He recalled observing instructor diagrams in his own education yet never used graphic organizers as a learning tool.

In his teaching CP adheres to the tenet that determining and building upon prior knowledge is crucial to meaningful learning (Ausubel, 1963). Furthermore, he challenges students to reconsider their past beliefs based on the premise that true conceptual change does not occur without disequilibrium or cognitive dissonance (Piaget, 1977; Posner, Strike, Hewson, & Gertzog, 1982). He offers this commentary:

> Intuitive learning supposes the mind is NOT a tabula rasa—the empiricist's blackboard. Knowledge is not information; information is food for thought—but there must be thought to turn information into knowledge. This means that the process of teaching is that of arousing this intuitive power in the students' minds, which is accomplished by getting them interested e.g. if possible, by presenting a classroom lesson by way of a problem which shows the need to learn it. I need to get them to think for themselves, which begins by creating inner dissatisfaction with what they already think they know.

Assessment in CP's course is based on providing clear expectations and includes class participation in discussions, reading responses, essays, and written tests and exams.

This classics professor teaches a unit of study on Greek mythology. His first exposure to concept mapping was during an action research project in his course (MacKinnon & Provencal, 2009). In a workshop setting, the instructor and students were led through a series of simple examples of concept mapping using Inspiration® software, a tool readily available on the campus computer network. The task posed to students was to create a genealogical map relating the Greek gods they had studied in class. On a second level, the god relationships were hyperlinked to themes that permeated the discussions of the Greek gods (see Fig. 19.6a, b).

The initial reaction of CP to concept mapping included:

> I was surprised to discover how one-dimensional my approach was to it [concept mapping] in the introductory learning session—analytical rather than synthetic; linear reasoning rather than imaginative concepts. The primary use I expected to make of it was to create a kind of taxonomy of detailed information. What I found more difficult was to use it as a brainstorming tool.

As the research project progressed, CP saw the organizational value of the concept map but continued to be skeptical about its potential for creative thinking. When probed to elaborate, it became clear that CP preferred to teach in a more "organic" fashion where ideas were pursued in class based on not only the reading at hand but moreover the "students' questions." As a curriculum tool, he found concept mapping to pose uncomfortable structural constraints particularly if it was used as a professor's framework for students to follow as the course progressed. The initial rationale for using concept mapping was to help students keep track of the emerging themes in the course; the Greek gods simply provided vehicles to enter into discussions about those themes. The concept map was intended to provide a graphical account of the knowledge "territory" that had been traversed.

In future offerings of the course, CP's recommendation (MacKinnon & Provencal, 2009) was to negotiate the concept map on a regular basis with students (perhaps after each week of lectures), an approach which would capitalize on engaging students to drive the curriculum based on their interests. In effect, CP wanted to more closely integrate the mapping exercise as a guide or template, yet maintain a certain

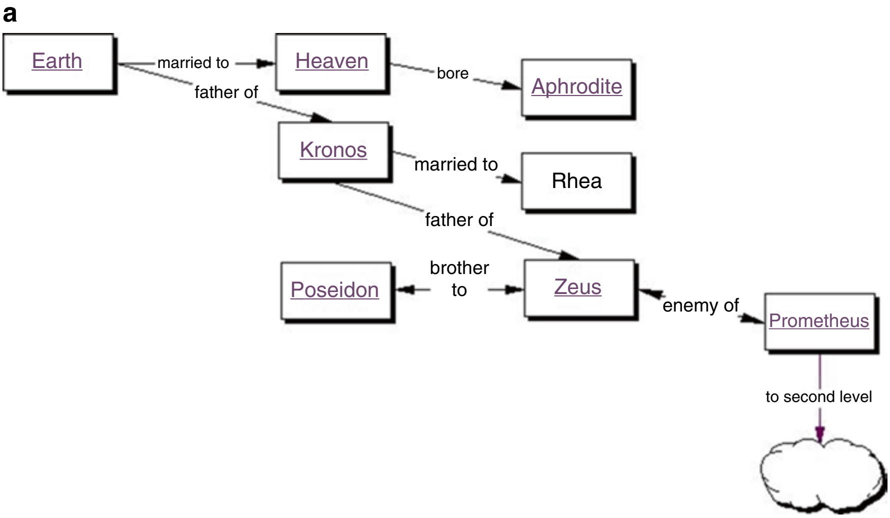

Fig. 19.6 (**a**) A genealogical map of the Greek gods. (**b**) Thematic analysis of the god relationships

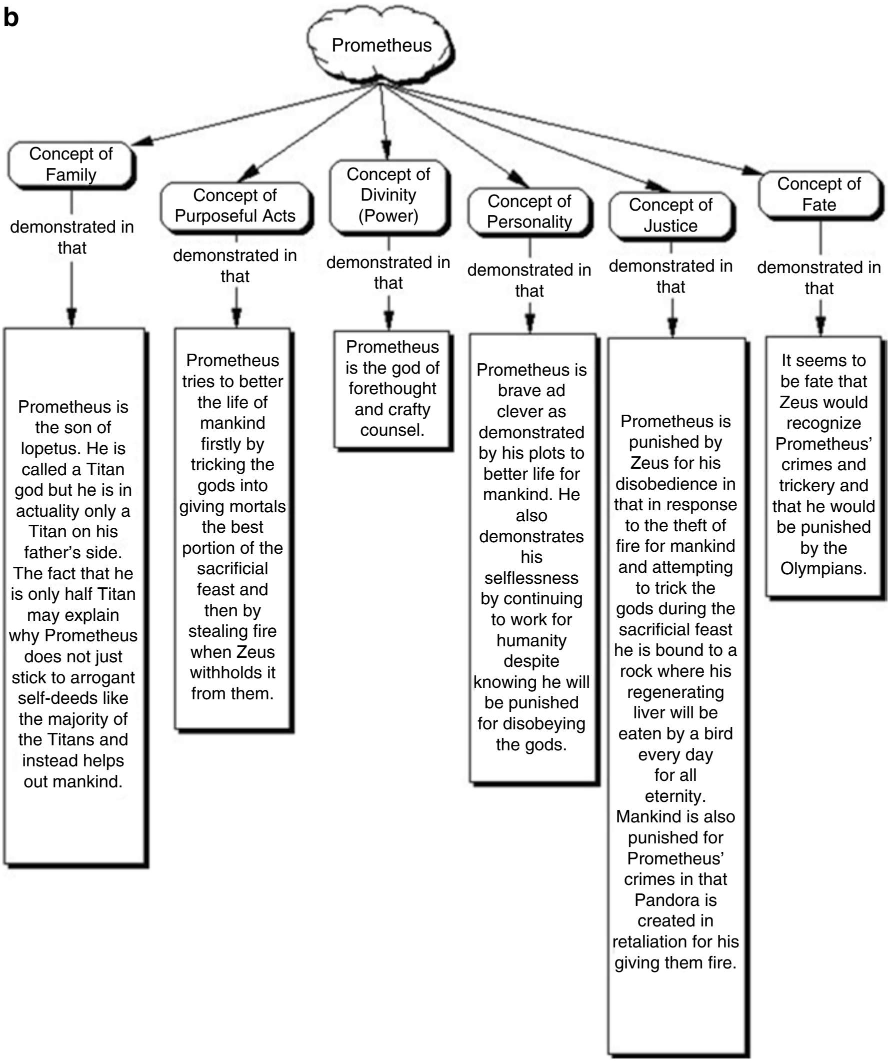

Fig. 19.6 (continued)

malleability to extend the learning rooted in emergent student interests. As a summative statement CPO offered:

> On a superficial level, CM [concept mapping] seems best suited to 'thematic' approaches e.g. what are the themes in a novel, motifs, conceits, etc. I find that is of itself a superficial approach to a literary work. My own approach is to discover what are the philosophic assumptions contained in a work, what is moving in the course of the narrative that binds individuals and their actions together etc. If I could find a way of using CM [concept mapping] to enable that approach, I would be happiest with it.

4.4 Empowering Architecture Education with Concept Mapping

The architecture professor (hereafter AP) in this study has a teaching philosophy deeply rooted in a blend with the practice of "being an architect." He teaches via both traditional lectures and studio design approaches in a Jamaican university of approximately 10,000 full-time and part-time students. He offered this insight into the nature of architecture as a subject:

> I am alternatively a teacher who practices architecture or an architect who teaches. This depends on the context I find myself sometimes by the hour. I have been teaching, practicing and researching architecture for at least 18 years and during this time I have developed attitudes towards design practice, teaching and research that when taken together reflects a personal multifaceted view of how architecture is, could or should be. This view of Architecture (which emphasizes temporal and spatial context) determines how I subsequently present (teach), produce (practice) and examine (research) design. My teaching therefore cannot be divorced from my "designerly" thoughts.

The most influential ideas surrounding AP's teaching include a recognition of a range of learning levels and styles, reflection, the notions of discovery, critical thinking, collective learning, and the use of technological teaching tools. Of these considerations, reflection is a key focus as alluded to here:

> One of my teaching strategies is the conscious use of reflection as a tool of learning for both myself and the student. In all courses that I teach there is at least one assignment that requires the student to reflect on the learning encountered, the environment (mental, conceptual) in which the learning occurred and comment on it. I have found this extremely beneficial to the student and it also provides me with an excellent means through which to gauge individual learning in the class. From my own perspective, my use of reflective teaching indicates a deep interest in constant improvement and dedication to creating new effective methodologies for teaching.

Architecture necessarily involves design, and AP has been committed to incorporating technological tools to support and complement lectures, discussions, and peer interaction. He notes that "this includes substantial use of video, and electronic images which serve to stimulate discussion and understanding as well as provide tangible examples for concepts." In his studies and teaching, he has relied heavily on the use of diagrams and knowledge maps, a precursor to his most recent experiences with electronic concept mapping:

> Drawings are used by the designer to think about and develop ideas through abstract representation. This can be seen as a way of thinking. A significant skill for a designer to acquire is the translation of ideas into the appropriate abstraction.
>
> Diagrams are essentially visual abstractions that depict concepts and objects. Diagrams help designers to explore alternative solutions and encourage visual thinking. By simplifying complex notions into elements and relationships through reduction and abstraction, a diagram becomes an economical way of dealing with large amounts of information.

The initial exposure of AP to knowledge mapping is related to organizing thoughts around writing as part of his doctoral thesis. To that point he had not used mapping as a learning tool. Most recently, AP was exposed to a professional development workshop on concept mapping curriculum. In the workshop, he was tasked to map the concepts from a single course that he taught. From this experience, his preliminary reaction was that the summative nature of architecture knowledge could be articulated in a concept map; however, he could not see the utility of using concept maps for gauging the "processes" of architecture. His analysis of the approach is captured in the following comments: "benefits were seen in a literary sense only and not in a visual-spatial sense," "best used for concepts that dealt with categorization or classification," and "… hard to think about uses in the studio beyond theoretical concepts."

This lecturer has persevered in terms of using concept mapping for curriculum planning but posits his most successful application has been to employ concept mapping as a graphic organizer in a "research and dissertation" module in his graduate level teaching.

In the final year of the Masters of Architecture program, students are required to pursue an in-depth research project related to the theory and/or practice of architecture. The culminating 10,000 word document includes a research problem, literature review, methods, analysis, and conclusion. Typically students have difficulty getting into the process of writing. Says AP:

> With very little practice at research and writing (it is a professional degree with lots of emphasis on design) I find the concept map helps the students create a clearer image of their research path. I guess the "creative, non-textual" background of the students allows them to receive great benefit from looking at information in a graphical (non-threatening) way. I guess it resonates with the students since they use diagrams a lot to represent complex assemblies (issues, concepts, processes…) in design studio.

It seems clear from the above comments that these architecture students have a natural disposition to using diagrams and pictures to express their ideas. Concept mapping, for the purposes of creating a digital knowledge map en route to preparing a formal report, is not only practically useful but also assists in getting students over the hurtle of academic writing.

5 Is Electronic Concept Mapping Generically Useful: The Issues

In this study all four educators used electronic concept mapping as a digital knowledge map. In all cases, regardless of content teaching area, the participants saw the value of using this approach for curriculum planning. They each felt that using such a graphic organizer forced the user to articulate the "hierarchical way" he/she thought about the key concepts. This was coupled with assertions that concept mapping was an effective means of so-called backwards curriculum design (Wiggins & McTighe, 2005) where the educator begins with the concepts (i.e., curriculum objectives) followed by a consideration of how to assess the learning and finally how will these concepts be taught. Several noted the advantage of seeing the entire unit of study in one place and recognized that visual learners, themselves included, would find this a valuable synopsis of the main ideas. In a related study (Forsythe & MacKinnon, 2005), students suggested that typically they forgot what they studied in the beginning of a chapter whereas creating a concept map allowed them to see the importance and relationship of all concepts throughout the book chapter. The thematic analysis in the aforementioned Greek classics classroom was similar in that students used the concept map to track recurrent themes in their study of the gods.

By all accounts, generating information-rich propositional phrases and creating cross-links in the concept maps were challenging for these educators regardless of the context. In probing these two challenges, some interesting issues arose. First, the participants again saw a great potential in cross-linking concepts. Paraphrased, both ELP and CP said "I try to remember to bring up an important point later in the semester for comparison purposes (perhaps a similar theme in another context) but often I forget; the cross-linking in the concept map helps me and my students to carry forward the comparisons because we have a graphic to refer to." In addition said ELP, "in teasing out the cross links, I felt better prepared to engage my students in a complete discussion; it helped me to clarify the complexity of the ideas." Research (Kinchin et al., 2000) has correlated sophistication of cross-linking to levels of critical thinking in the user; thus this challenge is common. A second hurtle for these educators was generating meaningful propositional phrases to provide rich relationships between concepts. By their own admission, they became, or felt they would become, more adept at this with practice. Phrases such as "includes" or "leads to" were common in their own concept maps. These lend little understanding to the complexity of relationship between most concepts. Therein lies a possible explanation for a frequently mentioned critique of concept mapping. Several of the study participants suggested that whereas content was relatively easy to categorize in a map, their subject areas inherently possessed a significant amount of "process-oriented" knowledge. They found that this type of sometimes tacit knowledge was difficult to articulate in a map. When first attempting concept mapping, it is not immediately obvious that concepts in themselves can be processes. For instance, the word "diagnosis" certainly embodies a process and could be a representative concept in a concept map for sports injury. More importantly though, propositional phrases (i.e., linking the concepts), when constructed carefully, lend a considerable "active sense" to linking the concepts. An example of such a concept–propositional phrase–concept might be "classification-determined by the scientific method leads to- species differentiation" or "fractures-through comparative radiology -can confirm-diagnosis." In both examples the propositional phrase implies a particular process. The point to be made here is that early adopters of concept mapping, regardless of the "nature" of their subject area, are not as likely to recognize this potential much less capitalize on it. Having said this, those adopters whose curriculum tends to be less rooted in process will probably find that concept mapping is a better fit for their mental map of the content area.

A recurrent criticism of concept mapping in this cohort of interviewees was the "reductionist" nature of the electronic concept map. The English literature and classics professors saw their classroom styles as emergent and highly dependent on student queries and has a certain open-endedness that allowed for exploring knowledge base impacted by analogies and examples. While they admitted that they arrived to a lecture with a mind-map of the "terrain" they would traverse, they balked at the notion that a formalized precursor concept map might "direct" much less constrain the "organic" nature of their professor–student interaction. Having expressed this, the English professor, for example, created a most elaborate concept map for a sonnet he was about to teach. So elaborate that even he was surprised by his own breadth of tangential knowledge to the topic. In the end he had to admit that he couldn't possibly have remembered all the connections and related ideas in a lecture so it may be quite useful. But how so? In discussions with these arts professors, it was clear that there was a tension between structuring the thought and relying on a structure (digital knowledge map) to guide discovery. As with most technologies, their effectiveness hinges on the foundational pedagogy that is employed. It was suggested that these educators might consider the range of possible uses of the concept map. This might include but is not limited to the following:

1. An instructor-prepared concept map distributed to students before a unit of study. This may be a complete "knowledge road map" or the instructor may leave parts of the map purposefully incomplete with the expectation that students would interact with the material and the lectures to "flesh out" the ideas.
2. The instructor may "negotiate" a concept map with students and their peers after each new topic is completed in a unit. On a weekly basis the instructor may work with students to accommodate new knowledge as they build up their concept maps.
3. Students may work together to create a concept map of the material as they understood it. This could be used as an assessment item for the instructor to see whether students have understood the nuances of the ideas. Qualities of concept maps have been quantified in the literature using criteria of semantic and topological taxonomy (Miller & Cañas, 2008).
4. Individual students could create their own concept maps of the learning they had accomplished. This may be submitted as a way of planning a term paper or replacing the paper altogether. The literature (Lopez, 2008) provides a means for evaluating a student map by comparison to an instructor map.

In general the anesthesiologist and architect found the concept mapping of content knowledge to be very logical, an extension of graphic organizers they would have experienced in a highly categorized and hierarchical science-type curriculum. They were less concerned about the reductionist nature of the tool and more concerned that the practical aspects of their fields of study could not be captured in a concept map. The anesthesiologist clarified by explaining that student's summative experiences in a plethora of operating room cases culminate in a problem-solving professional and the mere complexity of how that "gels" is difficult to articulate in a concept map. From a similar perspective, the architect found it difficult to create a map of the complex interplay of the practical processes that bridge anesthetics and design. In both instances the participants were forthright in suggesting that they were inexperienced in using concept maps but that at "first glance" it was not a trivial task to express processes in this graphic organizer.

5.1 What Do Students Say About Concept Mapping?

The instructors in this study shared some feedback they had received from students with regard to using concept maps. Most students found the software (Inspiration®) for creating maps very easy to use. Students were near unanimous in suggesting that the process of hierarchical mapping took time and practice to understand. Students suggested that in particular the graphic made it easier to see all the content they were responsible for. The most frequent critique was that good propositional phrases (linking the concept boxes) were difficult to create. Over half of the students in the arts classes revealed that many professors would prefer not to show their concept map (interpretation of curriculum) because of their power position as lecturer. These professors countered that opinion saying they preferred not to predetermine students' interpretation of the curriculum by showing them "the teacher's way is the right way." Science students on the other hand suggested that their logic background and exposure to organized knowledge made concept mapping a good fit for the type of learning style they were use to. They also noted that their professors would feel quite comfortable concept mapping with them. This small sample of students seems to be implying a tension in different subject areas based on the notion that some professors might be somewhat reticent about revealing their analysis ability while others would feel comfortable "thinking out loud" with their students.

6 Conclusions

The selection of participants in this study was purposeful in that the four educators were from different fields of study. This was important because often it is assumed that technological tools and their intended uses are perceived and worked with from the same pedagogical perspective (Becker, 2001). Each of the instructors in this chapter has shared a very different viewpoint on the relative use of concept mapping as a digital knowledge map yet there remain some common themes among them. The feedback is unanimous in suggesting that the pedagogy they choose to employ in their classrooms has a tremendous impact on how they see the potential of concept mapping curriculum. All four instructors share constructivist notions of engaging students in contextualized discussions that emphasize processes of critical thinking and their unwillingness to compromise that ideal by allowing the mapping process to entirely "steer" the teaching they do. Nonetheless it seems apparent that science-oriented subject specialists may have a higher comfort level with graphic organizers in general given the frequent occurrence of such in textbooks and their own formal education. As with many technology tools, educators often subvert the intended use and apply technologies in unique ways (Squires, 1999). When these educators saw (through discussions) that digital knowledge maps could be used in a variety of places within the sequence of their teaching model, the notion of the concept map constraining fluid teaching was replaced by a leveraging of the technology to promote constructivist practice which aligned better with their inherent teaching philosophy. It was evident in the end that this sample of educators was interested in extending their experience with concept mapping, further exploring the potential for this digital knowledge map to support good teaching.

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