CHAPTER 6

Cognitive Tools for Scaffolding Argumentation

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Argumentation is a complex ability crucial to critical thinking in virtually all academic subjects. It underlies scientific and philosophical discourse (Bricker and Bell 2009), and its use is explicitly required in almost every discipline studied in higher education (Wolfe 2011). Developing the ability to argue is recognized as an important goal at elementary, middle, and secondary levels (e.g., Berland and McNeill 2010; De La Paz and Felton 2010). By the time they start school, most children are able to give reasons supporting claims; and the ability to refer to evidence and respond to counterarguments develops throughout elementary and secondary schooling (Felton and Kuhn 2001; Kuhn 1992). However, unless explicitly guided to do so, many children and university students never develop more advanced argumentation skills such as identifying and understanding arguments presented in prose and constructing warrants (Asterhan and Schwartz 2007; de Vries et al. 2002; Maralee 2011).

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Technologies Scaffolding Development of Argumentation Ability

In this chapter we explore the potential of particular learning technologies—representational devices often referred to as cognitive tools—to advance students ability to argue and to develop subject area knowledge through argumentation. As technologies, cognitive tools are usually interfaces or media that allow users or designers to alter or enhance the way information is represented, and to do so in a way that potentially fosters learning. For example, in this chapter we describe how students can use simple tagging tools to mark and classify parts of an argument presented in text. In the research, we used a browser extension named nStudy (Winne et al. 2017) that allowed participants to tag text presented in html pages. They were able to tag content by selecting a text passage and choosing from nine labels (i.e., category names) preconfigured by the researchers.

Much of this chapter is concerned with the effects of using argument maps, diagrams, or interfaces that graphically represent the parts of arguments and how they are connected. Argument maps can be constructed by specialized authoring systems that offer considerable freedom in how an argument is visually shaped and spatially arranged (e.g., Argunet). However, in many instructional situations, interfaces that restrict the representation of arguments to a simpler, canonical form may be easier for students to learn and use. Two of us (Niu and Nesbit) designed an interactive web interface called the dialectical map (DM) that students can use to construct arguments. The DM, implemented in JavaScript, builds arguments in a consistent two-sided, pro versus con, pattern that has been shown to promote learning. We theorize cognitive tools such as argument tags and maps foster learning because they support the development of argument schemas.

Schemas

Schemas are hypothetical mental structures that cognitive psychologists recognize as encoding knowledge. Far from static, standardized modules, schemas are theorized to transform into new and unique structures as learners adapt to their environment and resolve discrepancies between assembled knowledge and new information (Dansereau 1995). Somewhat like a data structure that might be created by a computer programmer, a schema can potentially be constructed in whatever form is suitable for performing information-processing functions. Schemas are often depicted as combining semi-fixed, structural elements, and variable elements called slots. Learning may consist merely of changing the values in the slots and leaving the structure of the schema intact; or, when new information is inconsistent with the structure of the schema, the learner may search for and execute an adjustment to the structure of the schema in order to capture and more suitably represent the new information as knowledge. Construction and modification of schemas may be induced through interactions with the physical or social environment.

Schemas are the contents of long-term memory and are activated as needed for comprehension, problem-solving, and so on. One important function of schema construction is to aggregate and consolidate previously separate, simple schemas so the information they represent can be simultaneously activated in a single "chunk", thereby imposing less cognitive load on working memory.

Schemas are involved in learning both conceptual and procedural knowledge (Anderson et al. 1978). In the context of argumentation, a conceptual schema might be activated to identify and parse a claim-evidence relation that a reader encounters in text. A procedural schema, called a *script*, might guide a writer in generating a claim and then searching source documents for evidence supporting the claim.

Of the schema-related cognitive processes we have just described, it is schema construction—assembling and modifying schema structures so they are optimally adapted to the environment and to the goals adopted by the learner—that is the most difficult and has the most profound consequences for successful cognitive development. Consequently, scaffolding schema construction and consolidation is the type of instructional intervention that may offer the greatest benefit to learners.

Cognitive Tools: From Schemas to Software

Cognitive tools were conceived by Vygotsky as culturally evolved and socially transmitted ideas that mediate the relationship between learning, instruction, and cognitive development (Vygotsky 1978). In this view, cognitive tools are common in every school subject, examples being the number line in mathematics, foreshadowing in the study of literature, and the golden rule in ethics. Vygotsky argued that it is the specific characteristics of cognitive tools more than innate maturational tendencies that direct the path of cognitive development.

According to Arievitch and Stetsenko (2000), the research of the Russian psychologist Gal'perin can be credited with advancing the theory of cognitive tools initiated by Vygotsky. Vygotsky and Gal'perin understood that cognitive tools are not acquired by a copying process, but rather they are instructionally induced through interactions with others in relation to a task and an environmental setting. Observable actions, events, and conditions are internalized as mental symbols that are assembled to form a socially shared cognitive tool.

Gal'perin claimed that the major barrier to learning in typical instructional settings is that the scaffolding provided for knowledge construction is incomplete (Arievitch and Stetsenko 2000). Often, instructional support only represents the components of the learning goals that are overt and directly evident in the performance of those who have acquired the schema. They fail to represent implicit but necessary knowledge. Thus, learners are often left to discover the missing knowledge on their own by inefficient means such as trial and error. Gal'perin claimed that instruction can be significantly improved if students acquire cognitive tools that represent all implicit contextual cues, criteria, mental actions, and decision rules needed to perform a task. Gal'perin's research demonstrated that children guided toward complete and sufficient cognitive tools were able to master tasks more rapidly and efficiently. A key advantage of supporting acquisition of complete cognitive tools is that students can immediately begin solving whole problems without the need for extended prelearning of part-tasks. In this respect, Gal'perin's theory somewhat aligns with the instructional design model advocated by van Merriënboer and Kirschner (2007) which prioritizes whole-task instruction while allowing for part-task practice where necessary.

But cognitive tools that offer sufficient and complete guidance to perform a narrowly defined task do not necessarily support transfer of learning to related tasks. Gal'perin argued that cognitive development only occurs when learners acquire cognitive tools that represent the conceptual reasoning that generates the procedures to solve specific problems. Here, we see alignment with the mindful transfer of learning advocated by Solomon and Perkins (1989). Cognitive tools that support this type of general understanding emphasize analysis of conceptual distinctions. Where a complete cognitive tool of the first kind might allow a child to learn addition fluency in base ten, a cognitive tool of the second kind might enable the child to add in a number system of any base. Beyond guiding *when* and *how* to carry the result of addition in a single column, the more advanced kind of schema gives the *why*.

In the 1990s, English-speaking educational technology researchers adopted the term cognitive tools to describe tangible supports for learning provided in an instructional environment (Lajoie 1993; Jonassen and Reeves 1996). Consequently, at least in the English-speaking educational technology research community, the term cognitive tool no longer refers to culturally shared knowledge but instead to an objective, computer-mediated representation intended to foster development of schema. This new understanding of cognitive tools developed as part of a shift toward constructivist theory in educational technology research. Cognitive tools were presented as computer-based, learner-centered aids for knowledge construction. However, a search of recent educational technology research can readily demonstrate that the term cognitive tool is now applied to a wide range of educational software, often with no reference to its psychological roots.

In this chapter, we use the term cognitive tool to describe interactive computer programs designed such that usage by a learner induces construction, activation, or instantiation of a schema having particular properties. This definition implies that the process of designing a cognitive tool is guided by an analysis of the explicit and implicit decisions, actions, events and conditions comprising the goal task. Further, if we are to meet Gal'perin's criteria for transferable or generalizable knowledge, the analysis should examine the conceptual underpinnings of the task and, where possible, represent in the cognitive tool the means to performance in a wide range of circumstances.

Scaffolding Argumentation with Tagging Software

Cognitive tools are often regarded as visualizations that concretely represent interrelations among abstract concepts. That is ostensibly the case with argument maps, the category of cognitive tools with which we are chiefly concerned. However, argumentation can also be scaffolded by tools that do not present elaborate visual structures. For example, there may be cognitive benefits from using tools that label (i.e., tag) terms and phrases that learners judge as relevant to a task (Nesbit and Winne 2008).

Previous research in our laboratory (Mao et al. 2010) investigated whether learners' text tagging predicted reasoning they demonstrated in a subsequent essay about the ideas in the studied text. Undergraduate students were randomly assigned to a study group, a summarize group, or an argue group. All participants were asked to study hyperlinked web documents that explained competing theories about the origins of Hobbit-like

Table 6.1 Nine tags available to participants

Study tags	*Summary tags*	*Argument tags*
Difficult to remember	Main idea	Supporting claim
Detail	Key term	Counterclaim
Example	Explanation	Evidence

hominid fossils found on Flores Island (Homo floresiensis). The study group was instructed to use the text to prepare for a recall test. The summarize group was instructed to prepare for writing a summary of the text. The argue group was instructed to prepare to write an argument. Participants accessed the web documents via nStudy which has a feature learners can use to tag text (Winne et al. 2017). All participants were provided with nine tags they could use to color-code (i.e., highlight) terms and phrases in the web documents. Each of the nine tags appeared as text highlighting of a unique color. As shown in Table 6.1, there were three study tags, three summary tags, and three argument tags. Participants were free to use all nine tags regardless of their group membership. They were not instructed to use particular tags, and the tags were listed in alphabetical order (i.e., not organized as in Table 6.1). After studying, the participants completed recall tests, and then were given 15 minutes to write an essay evaluating the competing theories presented in the web documents.

The results showed that the different instructions given to participants affected their tagging behavior. Representing the frequency of each type of tagging as a proportion of their overall tagging, the study group did more study tagging than the other groups, the summary group did more summary tagging, and the argument group did more argument tagging. There were no significant differences among the groups on multiple choice or free recall tests, but in the essay the argue group provided significantly more reasons and other markers of the quality and quantity of argumentation than the other groups. A regression analysis found that even after controlling for group membership participants who made greater use of argument tags while studying subsequently provided more reasons in their essays.

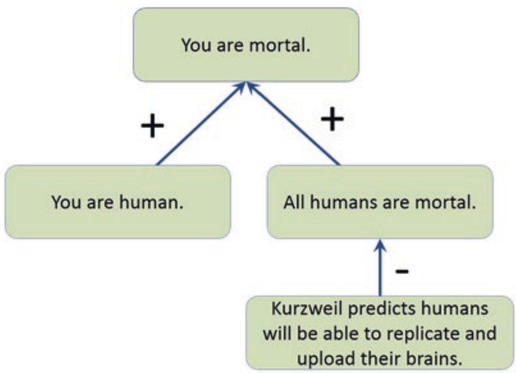
The significance of this research on scaffolding argumentation is that although the three groups retained and recalled similar amounts of information, the way they encoded the information as they studied—represented by how often they used argument tags—determined how well they were later able to use the information in forming arguments. The results are consistent with the theory that learners who study with an intent and expectation of arguing encode new information in argument schemas and later retrieve and apply those schemas when forming arguments.

Argument Maps

In their most common form, argument diagrams or argument maps consist of (a) text boxes containing sentences that present claims, reasons, or evidence; and (b) arrows connecting the boxes that denote the relationships among them (Andriessen and Baker 2013). Although they may be superficially similar to concept maps, argument maps differ greatly in form and function. A text box or node in a concept map typically contains a single noun phrase representing a concept, and usually a pair of nodes connected by a verb phrase is required to represent a single proposition. In contrast, a node in an argument map contains at least one proposition, and nodes are connected by a much more restricted set of relations perhaps consisting only of a supporting relation indicated by a plus sign and a contradicting relation indicated by a minus sign.

Figure 6.1 shows a simple argument map assembled from a few related propositions. It should be apparent that, unlike the syllogisms of deductive logic, the inferences and conclusions of argument maps are uncertain and demand subjective judgements about the truth of their propositions and the relevance of their connections. For example, the impact of Kurzweil's (2005)

Fig. 6.1 A simple argument map



prediction on your belief in human mortality depends on the degree of credibility you assign to Kurzweil as a futurologist, which in turn depends on how much you know about Kurzweil's credentials and previous predictions.

Since its earliest use in instructional systems such as Belvedere (Suthers et al. 1995), argument mapping has been seen as a way to support collaborative learning. In such systems argument maps are used to mediate debates or discussions that occur via specialized computer-based communication systems (Scheuer et al. 2010). Other argument mapping systems such as Reason!Able (van Gelder 2002) have been designed for individual learners to analyze arguments in texts or practice constructing arguments. Our research investigates individual use of argument maps with the goal of understanding how visually representing arguments affects learning and cognition.

Refutational Maps and Conceptual Change

One of the key findings in science education is that refutational text (instructional text which explicitly refutes a persistently held misconception) is more effective in promoting conceptual change than otherwise similar text which merely explains the intended scientific conception (Guzzetti 2000; Hynd and Alvermann 1986). Refutational text is inherently argumentative in the sense that it introduces claims and explicitly supports or opposes them by presenting reasons or evidence. Liu and Nesbit (2012) investigated the extent to which conceptual change can be promoted by studying a *refutational map*. We conceive a refutational map to be refutational text presented in the form of an argument map.

The study materials used in the research were adapted from texts on Newtonian laws of motion used in previous research on conceptual change (Alvermann and Hynd 1989). Participants were randomly assigned to an expository text group, a refutational text group, and a refutational map group. All three groups studied the concepts of Newtonian motion using a learner-paced presentation. The expository text group studied a text presentation that did not mention common misconceptions about the movement of objects. The refutational text group studied a text presentation that included all the text seen by the expository text group plus text that identified and refuted common misconceptions about the movement of objects. The refutational map group studied the same refutational text, but it was presented within the nodes of an argument map. Figure 6.2 shows a portion of the refutational map. The concepts of Newtonian

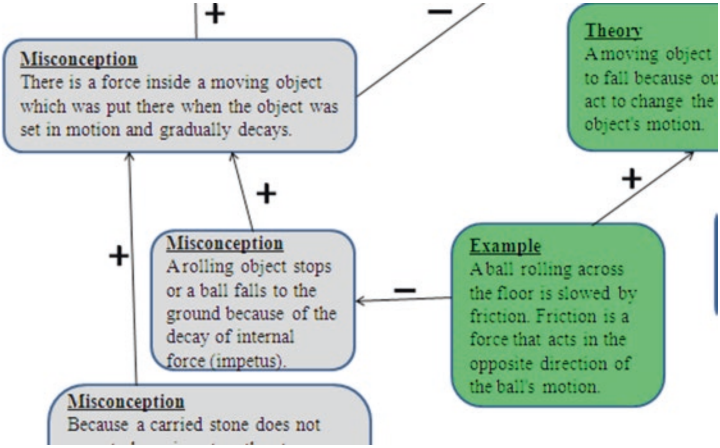


Fig. 6.2 A portion of the refutational map

motion appeared in green-colored nodes. Common misconceptions appeared in gray-colored nodes and were labeled as misconceptions. Supporting relations among Newtonian concepts were labeled with plus signs, as were supporting relations among misconceptions. Each Newtonian concept or example that contradicted a misconception was linked to the misconception by an arrow labeled with a minus sign.

After the study phase, all groups were given a free recall test and a knowledge transfer test that required application of Newtonian concepts of motion to qualitatively reason about physics problems. The refutational map group scored significantly higher on the free recall test than the other two groups. On the transfer test they scored significantly higher than the expository text group but not the refutational text group.

Prior to the study phase, the participants were given the Test of Logical Thinking (TOLT, Tobin and Capie 1981), a test of quantitative reasoning that previous research has found to correlate with conceptual change relating to force and motion (Park and Han 2002) and other topics in physics (Kang et al. 2004). Our research found that the TOLT predicted performance on the free recall test ($r = .47$) and transfer test ($r = .45$). Interaction analysis found that the TOLT moderated the treatment effect for the transfer test but not the free recall test. For the transfer test, participants who had scored below the sample median on the TOLT received more benefit from studying the refutational map than those who had scored higher on the TOLT. Further analysis of the transfer test scores found that among participants who scored lower on the TOLT, those who studied the refutational map significantly outperformed those who studied the refutational text (d = .73). Furthermore, the use of the refutational map by these participants raised their transfer performance to approximately the same level as the performance of participants who scored higher on the TOLT.

Why would the refutational map help learners with low prior ability to perform so well on the key measure of conceptual change? Both the refutational text and map interspersed and explicitly connected the claims of naïve theory with the specifically opposing claims and evidence of Newtonian theory. We speculate that the graphical features of the map—the boxes delineating separate ideas and the arrows specifying the relations among ideas—were more effective than the connectives and other verbal devices in the text in helping participants to construct or complete argument schema. We do not believe argument maps should be regarded as pictures of argument schema, but they may be information structures that can be more easily assimilated into argument schema than equivalent texts because they do not require the learner to make as many inferences in the assimilation process. The explicit labeling of misconceptions, support relations, and contradictions in argument maps decreases learners' reliance on context and the interpretation of somewhat ambiguous textual cues. Also, the features of the refutational map signal more clearly that the presented information is intended to be encoded in an argument schema rather some other schema.

The type of node-link format we used to construct the refutational map may not be ideal. As with node-link concept maps, a map containing a dozen or so links can appear dauntingly complex (Nesbit and Adesope 2013). Reading node-link maps, unlike the consistently linear structure of prose, requires frequent decisions about which links to follow and when to jump to a distantly connected node even though readers may have no heuristics on which to base their navigational decisions. One of the goals of the research we describe in the next section was to develop and investigate a type of argument map that is more readable and also represents more of the kind of the information used by expert arguers.

Resolving Thesis and Anti-thesis with the DM

We propose that the most effective cognitive tools are those whose repeated use shapes cognitive schemas which are optimal for solving a particular class of problems. As tools, they must be designed (or have evolved) so the learner can focus on the problem at hand and is not distracted by features of the tool not relevant to the problem. As scaffolds, they must be designed so that the more they are used the less they are needed. We have already described how the typical node-link format often produces a difficult-to-read representation of an argument, so how might an argument map be structured to serve as a more effective scaffold for advanced argumentation?

Designing the DM

Many argument maps focus on representing the evidential relations among components of an argument and offer no guidance on how to present both sides of the argument or how to resolve thesis and antithesis. Lack of scaffolding may work for sophisticated arguers, who tend to habitually synthesize and balance arguments and counterarguments, but for less skilled arguers the lack of scaffolding may lead to confirmation bias (i.e., attending only to information that supports their position) and arguments that fail to address opposing claims.

The Vee diagram (Novak and Gowin 1984; Nussbaum 2008) was designed to support argument-counterargument integration. In the Vee diagram, arguments are organized on the left side and counterarguments on the right. Related arguments and counterarguments (i.e., reasons that specifically contradict each other) can be placed in the same row. There is also space at the bottom of the diagram for writing a final integrated conclusion or rationale. A learner who focuses only on one side of an issue and fills out only one side of the Vee diagram is prompted by the remaining empty space to develop the opposing side of the issue. Although the Vee diagram prompts the learner to attend to counterarguments, it lacks scaffolding for other important aspects of skilled argumentation. It offers no representation of (a) warrants, (b) the hierarchical substructure of arguments whereby evidence can support reasons which in turn support claims, (c) the differing strengths of supporting reasons or evidence, and (d) the ordering of reasons for rhetorical purposes. What type of cognitive tool might scaffold argument-counterargument integration like a Vee diagram but also foster learning of other aspects of advanced argumentation?

To achieve this design goal, Niu and Nesbit developed a new type of argument map called the DM (Niu et al. 2015). The DM, which is implemented as an extension of a web browser, borrows several features from the Vee diagram. As shown in Fig. 6.3, a primary claim or question ("should corporal punishment be outlawed") can be entered at the top, by either an instructor or a student. The reasons supporting the primary

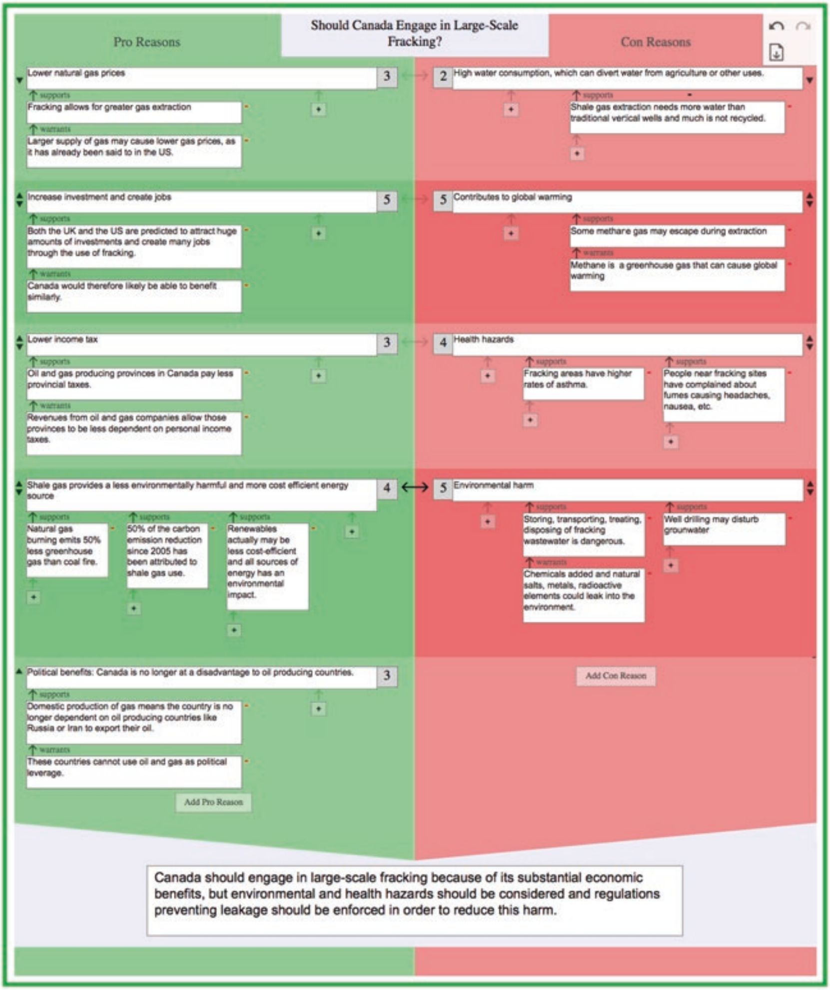


Fig. 6.3 An example of a dialectical map constructed by a research participant

claim are organized on the left side, and those contradicting it are entered on the right side. A conclusion that integrates the positions of the pro and con side can be entered at the bottom.

Interactive features of the DM were designed to exercise argumentative skills such as estimating the strength of support that a reason brings to a claim, generating counterarguments, distinguishing warrants from evidence, and integrating arguments and counterarguments. After a learner enters a reason they can select its strength of support on a scale from 1 to 5. The learner can put reasons in sequential order, perhaps to match how they will be presented in an argument essay to be written later. To aid integration and resolution of pro and con, pro reasons can be bound to related con reasons so that they travel together when one of them is pulled higher or lower on the page.

Assessing the Effects of the DM

An experiment reported by Niu et al. (2015) investigated how using the DM to study affected students' subsequent writing about the ideas in the studied text. University students who participated in the research were randomly assigned to a DM group, an argument group, and a no-training group. Both the DM group and the argument group were trained in the elements of argumentation (i.e., claims, reasons, counterarguments, rebuttals, and warrants). Only the DM group was trained how to use the DM. All three groups were instructed to study a text on shale gas extraction and hydraulic fracturing to prepare for a test. Only the DM group was instructed to use the DM to study. As expected, during the study phase the participants in the DM group were active extracting and paraphrasing information from the source text and entering it into the DM. The other two groups read and highlighted content.

There were four main outcomes of the research. First, immediately after studying, the participants were asked to judge how much they had learned while studying. DM group reported significantly higher judgments of learning than the other two groups. Second, the participants were asked to write a summary of the studied text. The DM group wrote summaries whose organization more closely resembled an introduction-body-conclusion format, perhaps reflecting the ordering of the primary claim, reasons, and conclusion in the DM structure. The DM group also made significantly greater use of argumentative lexical markers such as "because", "however", "furthermore" and "evidence" than the argument group. Third, the participants responded to several cued recall questions about the studied text. The DM group recalled significantly more main ideas than both the other groups. Finally, the participants were asked several questions that required reasoning about the studied material. There was no significant difference in the number of reasons provided by each group. However, when the number of reasons was normalized by number of words, it was found that the DM group's responses had significantly greater reason density than those of the other groups.

We interpret these results as showing that using the DM as a study tool affects how information is stored in and retrieved from long-term memory. It is likely that activity of selecting and paraphrasing information would have helped the DM group to encode the ideas in the source text more meaningfully, no matter what structure the paraphrased content had been entered into. However, the type of schema in which the studied information was stored was reflected in the ways students recalled, summarized, and reasoned about the information. More so than the other groups, the DM group responded to the post-test in ways one might expect if they were retrieving information from argument schemas.

The DM Goes to School

The DM was used in teaching two writing-intensive, undergraduate, biology courses at Simon Fraser University (Niu et al. 2015). In each of three separate assignments, each student drew from assigned readings to construct a DM. The three DMs were scored by the instructor for their use of relevant evidence to support arguments. Students were given detailed feedback on the quality of their arguments and evidence. The biology topics covered in the DMs were assessed later in the courses. In both courses, the instructor reported that students increased the quality of argumentation represented in the DMs across the three assignments. Student's comments about the instructional use of the DM tool were generally positive, and many claimed that it helped them to improve their argumentation skills.

Implications for Instructional Theory and Practice

In broad theoretical terms, the results we have presented can be interpreted as examples of transfer-appropriate processing. Transfer-appropriate processing is the idea that knowledge is better remembered and applied when the particular semantic codes formed during encoding are suitable for or transferable to the retrieval context or post-study task (Morris et al. 1977). It relates to the more fundamental phenomenon of encoding specificity whereby knowledge is better remembered and applied when the conditions at time of retrieval match those at the time of encoding (Tulving and Thomson 1973). Schema theory, then, can be seen as an explanation, but not the only explanation, for many research results in which transfer-appropriate processing is observed or plausibly inferred. Viewed from this perspective, an argument schema provides the conditions for encoding specificity and the semantic codes for transfer-appropriate processing. The three cognitive tools we have investigated—argument tagging, refutational map, DM—function as scaffolds for the activation of argument schemas and assimilation of new information.

In the first experiment (Mao et al. 2010), we theorize that learners who were instructed to tag materials in a way that would prepare them to write an argument essay activated a pre-existing argument schema. Their tagging activity entailed cognitive processing that filled in slots in their argument schema. The prepare-to-argue task instructions and the activation of an argument schema during study would have primed learners to re-activate the argument schema when asked to write a comparative essay in the post-study test. Because an argument schema emphasizes evidence and other reasons supporting a claim, the learners in the argue group tended to provide more reasons in writing their essays.

In the second experiment (Liu and Nesbit 2012), we theorize the features of the refutational map-led learners to activate an argument schema and made it easier for learners with low prior ability to fill in slots in the schema. To achieve conceptual change, it is crucial that learners not only accept the concepts of Newtonian motion but also cognitively process contradictions between those concepts and the commonly held naïve theory of motion. Because learners in the refutational map group with lower prior ability were more likely to have filled in slots in their argument schema representing those contradictions and to have cognitively processed those contradictions, they were more likely to show evidence of conceptual change on the post-test.

In the third experiment (Niu et al. 2015), we theorize that training in the use of the DM and using it during the study phase activated an argument schema and facilitated encoding of information in the schema. When the argument schema was re-activated during the post-test phase, it led learners to write more lexical markers for argumentation. It may have also led learners to recall more main ideas as they were more likely to be encoded as claims or reasons than other ideas.

The foregoing types of explanations assume that learners have already developed argument schemas that are available for activation and use in an instructional strategy (i.e., "argue to learn"), but there is more to the story. Although we might assume that almost all school-age learners have the cognitive ability to recognize and apply the claim-reason relationship, we have also seen that understanding of argumentation in many learners is limited. They may fail to acknowledge and rebut counterarguments (Nussbaum 2008). They may fail to recognize and weigh the relative strengths of supporting reasons. They may fail to consider that the validity of reasons is conditional upon warrants, and so on. We propose that learners who have developed more sophisticated argument schemas that incorporate these features have an advantage in leveraging argumentation as a learning strategy. Assimilating information into argument schemas that make such distinctions requires more elaborative processing of the information, and more elaborative processing makes new information more meaningful and memorable. Thus, the success of argumentation as an instructional strategy crucially depends on the progressive development of learners' argument schemas (i.e., "learn to argue").

We have described how cognitive tools can scaffold the activation and application of argument schemas as an aid to learning subject area knowledge. We propose that the same kind of cognitive tools can scaffold the development of more sophisticated argument schemas. In theory, schemas are not rigid fixtures but are instead potentially subject to adjustment, modification, and extension whenever they are activated. When a learner uses a "counterclaim" tag to classify text, the learner's argument schema may be extended to accommodate counterarguments. When a learner studying a refutational map sees a contradicting link from observed evidence to a claim labeled as a misconception, the learner's argument schema may be extended to accommodate rebuttals. When a learner adjusts the strength of a reason in a DM, the learner's argument schema may be extended to represent evidentiary strength. If arguing about subject knowledge has the dual effect of developing students' subject knowledge and developing their argumentation abilities, we propose that using appropriately designed cognitive tools in such learning activities can boost that effect.

A qualification is needed. Although argumentation ability develops naturally as children discuss and debate with others, and it seems that suitably adapted experiences with argumentation tools may accelerate that development, we do not mean to imply that subtle nudges from an interface and repeated practice of argumentation as a procedural skill are sufficient for optimal development. Recall Gal'perin's insistence that cognitive development requires acquisition of the conceptual reasoning that lies behind and explains procedural knowledge (Arievitch and Stetsenko 2000). In addition to scaffolded practice, learners must have opportunities to study and reflect on the concepts that generate and inform the cognitive skill. Learners can probably learn to introduce warrants in argumentative writing having never considered their properties or how they relate to other types of reasons. However, learners' use of warrants will be more adaptable to varying and novel conditions if they have studied how warrants differ from other types of reasons and why expert arguers will make them explicit on some occasions and not others. Cognitive tools can introduce learners to specialized terms and prompt their use, but we do not believe they can substitute for an exposition and discussion that deals with the underlying concepts of argumentation.

The Road Ahead

An instructional implication of the theory we have investigated is that the process of learning to argue should be embedded across the curriculum, and wherever possible the same cognitive tools should be used to foster argumentation in different subject areas. Tool-enhanced development of an argument schema that occurs in one subject domain (e.g., chemistry) can potentially transfer and enhance learning another subject domain (e.g., history). Suppose a student learns the idea of a warrant when using a cognitive tool to write a laboratory report about a chemistry experiment which concludes that a substance increased mass as a result of heating. The student might record the warrant as "measuring a substance before and after applying heat and finding an increase in weight is strong evidence that, by some means, the heat caused an increase in mass." Later, when writing an essay for a history class, the student might find an analogy to the chemistry warrant. Using the cognitive tool, the student might record a warrant as "credible population estimates of an ancient city showing the population was higher before than after a recorded war are strong evidence that, by some means, the war caused a decrease in population."

Kuhn and her colleagues have shown that students' argumentation skills develop gradually throughout their years of schooling (Crowell and Kuhn 2014; Kuhn et al. 2016). This suggests that a cognitive tool intended to scaffold the development of argumentation ability should model each learner's stage of development and adapt its features accordingly. Perhaps such tools could proactively suggest the use of a feature when the learner model indicates that the learner is ready to benefit from it. For example, a tool might at first only offer a tagging feature with the single tag "pro" which the student could use to tag statements supporting one side of an issue. When the model predicts the student is ready, the tool might notify the learner that a "con" tag is available and explain the conditions under which it should be used. The adaptation of the tool to the learner's increasing argumentation ability would proceed in this manner until the tool's interface offers multiple feature that equal or exceed those in the DM.

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