

CHAPTER 25 – The Dendrogram Model of Instruction: On Instructional Strategies and Their Implementation in DeepTutor

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Introduction

We present in this chapter an attempt to conceptualize the notions of instructional strategies and tactics in a way that unifies various views held by different research communities. We then use the proposed conceptualization to describe the implementation of strategies and tactics in DeepTutor (Rus, D’Mello, Hu & Graesser, 2013a; Rus, Niraula, Lintean, Banjade, Stefanescu & Baggett, 2013b), the first ITS based on the framework of Learning Progressions (LPs) (Duschl, Maeng & Sezen, 2011). LPs have been proposed by the science education research community as a way forward in science. The proposed conceptualization of strategies and tactics is intended to help guide the implementation of strategies in GIFT (Sottolare, Brawner, Goldberg & Holden, 2012).

The gist of the proposed conceptualization is a dendrogram model of instruction in which strategies and tactics are defined at various level of instruction granularity resulting in a multi-level, hierarchical structure called a dendrogram. The proposed conceptualization also fits the general (dictionary) definition of strategy as “a plan of action or policy designed to achieve a major or overall aim” or “pattern in a stream of decisions” (Henry Mintzberg; from Wikipedia entry on Strategy), and tactics as local decisions about “actions” (to be precise, as local decisions to choose actions) in the plan shaped by the strategy. Strategies can be viewed as affecting the overall shape of the plan of action while tactics are local decisions resulting in actions. The types of tactics, their mixture, and their enactment are conditioned by the global strategy (which could be many) as well as other factors such as learning environment, target domain, and student background.

Probably, the closest definition of instructional strategy as defined in our dendrogram model is Dick and Carey’s (1996) definition of an instructional strategy as the process of sequencing and organizing content, specifying learning activities, and deciding how to deliver the content and activities. Our dendrogram model assumes that this process can be carried out at different levels. Example levels include sequencing and organizing content across grade levels (e.g., K–12 level), across courses within a grade (grade level), within a course (course level), inside a lesson (lesson level), or within an activity such as problem solving. That is, we can talk about strategies at all these different levels of instruction granularity. In our narrative here, we emphasize cognitive (processing of target content) and social aspects of learning and pay less attention to other important components of learning such as affect and motivation. This is primarily due to space constraints and our intent to build on our experience with developing DeepTutor, which for now addresses primarily cognitive and social aspects of learning.

The chapter relates, within the space constraints, the implementation of various instructional strategies in DeepTutor to the GIFT recommendations (Sottolare et al., 2012). According to GIFT designers, there is a distinction between strategies, which are general (e.g., ask a question, prompt the learner for more information, or review basic concepts), and tactics, which are enactments of strategies in a specific domain (e.g., ask a question on concept B, prompt the learner for more information on concept B, or review basic concepts for building clearing tasks). The relation between GIFT definitions of strategies

and tactics and other conceptualizations of these terms is also elaborated as opportunities arise. A first comment on the relationship between our ideas presented in this chapter and the GIFT view of strategies and tactics is that all our descriptions of strategies and tactics are domain-independent while GIFT views only strategies as domain-independent.

We conclude the chapter with yet another model, an action model of instructional strategies and tactics, which we call the Fourier model. The basic idea of the Fourier model is that actions taken by tutors and which are directly visible to students are the result of mixing the effects of many individual strategies at multiple levels of instruction. This mixing of the final signal from simpler ones is analogous to how a final, complex signal is obtained, in Fourier analysis, from simpler signals, which correspond to simpler trigonometric functions. The ideas described here are presented in the context of conversational tutors targeting science learning. Nevertheless, they have wider applicability.

Related Research

There is a large spectrum of understanding of the terms strategies and tactics in the education-at-large literature, including the education, psychology, and education technologies literatures. These understandings vary from Foshay's (1975) early first-cut suggestion that there is only one instructional strategy to a myriad of other conceptualizations that use terms such as instructional methods, instructional mechanisms, instructional heuristics, instructional approaches, instructional strategies, pedagogical strategies, tutoring strategies, instructional tactics, tutoring tactics, and cognitive principles of learning. Furthermore, some of the reviewed works use the terms of strategy and tactic in underspecified, ambiguous, or interchangeable ways while others attempt to make a clear distinction between strategies and tactics albeit at different levels of instruction granularity. It is beyond the scope of this chapter to investigate thoroughly the differences among the various definitions and use of the terminology. Nevertheless, we review several conceptualizations of these terms by several research groups in two different communities and propose a model that is a first attempt to unify these various conceptualizations.

Education Literature

As already mentioned, according to Foshay (1975), there is only one instructional strategy and many tactics. The sole instructional strategy is to induce a situation for learning, which must meet the following four conditions of learning: drive or motive (student must want something), cue or stimulus (student must notice something), response (student has to do something), and reward (student has to get something). One can argue that this sole strategy of "inducing a situation for learning" is equivalent to Vygotsky's ZPD (1962). According to Foshay, tactics must meet these four conditions to fall within the umbrella of the "acceptable strategy" (note the circularity of the two notions of strategies and tactics). Foshay (1975) analyzes three tactics, called approaches, with respect to satisfying the four conditions: teacher-centered classroom, mastery-learning, and project-centered approach. For instance, Foshay indicates that teacher-centered classroom is weak at motivating students because this condition is limited to "pleasing the teacher" as students' main drive instead of targeting more personal and therefore more powerful drivers. This view is not entirely incompatible with others' use of the terms strategies and tactics. It is just that the granularity level at which strategies and tactics are defined is very broad.

According to Rothwell and Kazanas (1998), an instructional strategy is an overall plan that governs content (*What is taught?*) and process (*How will it be taught?*). Importantly, the strategy must be specified before content (instructional materials) is created. This makes sense to us, because, for instance, particular strategies or aspects of strategies in DeepTutor were implemented at authoring time as opposed to instruction time. That is, the implementation of some strategies in DeepTutor require steps taken during authoring (off-line), as suggested by Rothwell and Kazanas, in addition to during tutoring (online).

Rothwell and Kazanas (1998) categorize strategies at two levels of granularity, namely, macro and micro. A macro-strategy is an overall plan governing a course or module. A micro-strategy is a specific plan governing a unit such as one lesson. Rothwell and Kazanas (1998) define an instructional tactic as an activity that facilitates a strategy. They suggest that strategies can be considered in different ways. Based on the philosophy of learning and instruction, they differentiate between expository and discovery instructional strategies. Guided discovery, drill and practice, and inductive exposition are some examples of instructional strategies defined on the basis of philosophy of learning. Strategies can also be categorized based on events of instruction (Gagné, Briggs & Wager, 1992), i.e., what happens during learning and what type of learning is intended. The emphasis is on the link between such instructional events and learned capabilities such as verbal information, cognitive strategy, intellectual skills, motor skills, and new attitudes. We agree with the idea of a dual view (if not multiple views) of strategies without further elaborating at this moment.

Rothwell and Kazanas also present recommendations on how to select among many instructional strategies based on four factors: learners, learning outcomes, learning and working environment, and constraints of the instructional design process. Rothwell and Kazanas point out that any strategy can be adopted but that not all strategies work similarly well under various conditions. As we argue later, deciding which strategies to trigger at each step of the tutoring process is a very important task. Our Fourier model regards tutor's actions as the result of many strategies that are combined by tutors through a complex process (which is yet to be fully understood) that involves deciding which strategies to use and when and how to combine the effects of the activated strategies in ways that resonate with the learner. Examples of tactics that they provide and which were taken from Jonassen, Grabinger, and Harris (1990), are help learners organize information, use cuing systems, provide examples, vary lesson unit size, sequence instruction in logical order, and sequence instruction in learning prerequisite order. Rothwell and Kazanas' strategies and tactics are apparently domain-independent, which differ from the current conceptualization of strategies and tactics in GIFT.

A clear distinction between strategies and tactics is made by Merriënboer and Kramer (1987). Instructional strategies are general design plans that differ in their control of students' processing loads. On the other hand, instructional tactics are specific design plans describing methods to reach learning outcomes under specific circumstances. They mention three instructional strategies, which they call the Expert approach, the Spiral approach, and the Reading approach. These strategies were proposed in the context of computer programming instruction. Tactics were defined using a goal-circumstance-method format. Circumstances affect the outcome of methods but cannot be manipulated. Methods are manipulations designed to lead to desired outcome(s) in given circumstances. The goals in this format are skill-oriented, i.e., specifying what skills students would master in the given circumstances if the specified method is used. For instance, a tactic could be the following triplet (goal, circumstance, method): **goal**=mastery elementary programming background, **circumstances**=students have disadvantaged home backgrounds and are 8 years old or younger, and **method**=ask many factual questions that students are expected to answer correctly.

Intelligent Tutoring Literature

Graesser and colleagues (2001) enumerate a number of ideal tutoring strategies such as Socratic method, modeling-scaffolding-fading, reciprocal training, anchored situated learning, error diagnosis and remediation, frontier learning, building on prerequisites, and sophisticated motivational techniques. It should be noted that strategies and tactics are used interchangeably by Graesser and colleagues (2001) who end a paragraph that describes the above strategies with "tutors clearly need to be trained how to use the sophisticated tutoring tactics because they do not routinely emerge in typical tutoring sessions with untrained tutors." That is, there seems to be an implied similarity of strategies and tactics.

VanLehn, Jordan, and Litman (2007) make a crisp distinction between tutorial strategies and tactics. Similar to Foshay (1975), they mention only one strategy, which is broadly defined based on the structure of the tutoring activity of solving one problem (their system helps students solve physics problems). The strategy consists of two phases: 1) collaborative problem-solving and 2) reflection, which consists of the student and tutor discussing the solution. An alternative to this strategy is the following: prompting the student for a short-essay answer to a problem followed by feedback and worked-out solution (with no dialogue interaction). These two strategies are defined based on the structure (type and sequence of major phases) of the “solving one problem” activity in a tutoring session. One can imagine a mixture of these strategies too. As part of implementing a variable instruction strategy one could alternate between solving problems using the collaborative-reflection strategy and using the “prompt for short-essay answer followed by feedback and worked-out solution.” That is, some strategies serve other higher-level strategies. Our dendrogram model tries to capture this hierarchical relationship among strategies. For this example, the dendrogram model suggests that variable practice is a strategy applied at lesson level (which in this case is problem-solving) while the collaborative-reflection and the “prompt for short-essay answer followed by feedback and worked-out solution” strategies apply at the next level of instruction granularity, which would be the solution level in this case.

Tactics, according to VanLehn and colleagues, are micro-level decisions that control brief episodes of tutoring, such as a single step. Note again the granularity as a major differentiation factor. Examples of tactics are tell-or-elicite a step during problem solving, ask for justification of steps, generate feedback, and figuring out the type of question to ask. A policy is a set of actions, e.g., decisions with respect to tactics, that are to be taken by the tutor during tutor-student interactions. Policies that are successful at inducing student learning gains are sought. Importantly, in a more recent paper, VanLehn and colleagues redefine tactics as policies (Chi, VanLehn, Litman & Jordan, 2011). Nevertheless, we adhere to their earlier view of making a distinction between tactics and policies. As we mention later, we propose to use strategies, policies, and tactics to best describe the behavior of their systems and ours. Policies offer a characterization of a sequence of tactics similar to strategies. We define policies as strategies with a bias (as explained later). Policies may correspond to the control layer discussed in Collins, Brown, and Newman (1987).

We do recognize the above framework, with some alterations, in DeepTutor. For instance, our general strategy has two phases: collaborative problem solving and summary of the solution to the problem, which can be regarded as a worked-out solution. It should be noted that DeepTutor targets for now the domain of conceptual physics at high-school and college level. The second phase, solution summary, is just a summary without any interactive discussion. While the current design in DeepTutor resembles the two-phase strategy in VanLehn and colleagues’ design, we do intend to alter (à la VanLehn, Jordan & Litman, 2007) this strategy as we add in new strategies such as variable practice. In fact, instead of simply replacing this strategy, we plan to add new strategies and a strategy selection layer that will dynamically decide which strategy to use and when.

The four tactics mentioned in VanLehn, Jordan, and Litman (2007) are present in DeepTutor as well in various incarnations. The tell-or-elicite tactic, which is supposedly founded on the “scaffolding-modeling-fading” theory (which Collins, Brown & Newman [1987] call a teaching method, by the way), is present in DeepTutor in the following form: “elicite a step if not articulated by the student” and tell. That is, students are expected to mention all the steps of a coherent solution to a physics problem and if one of the steps was not articulated by the student DeepTutor always elicits it. DeepTutor always tells the step after either the student articulated it or the system elicited it. This is to assure that all the steps are in the common ground of the two conversational partners: tutor and student. Similarly, students are expected to justify their responses using physics principles, and if not, the system prompts them for a justification. In other words, in DeepTutor there are well-defined policies that emphasize students’ articulation of the solution and its justification. We elaborate later on what a policy is and its relation to strategies and tactics. For now, we simply note that “self-explanation” is a strategy, which may be implemented through

two tactics: tell-or-elicite and ask-for-explanation-or-not (both are binary tactical decisions). When the outcome of a tactic is set a priori (by the researcher or developer) then it becomes a policy, e.g., always ask for an explanation instead of dynamically decide to ask or simply tell. That is, the bias in the enacted strategy generated from (pre-) setting the outcome of certain tactical decisions leads to a policy, e.g., always ask for an explanation. The policy can also be dynamically learned in which case the bias would often be hard to interpret; this is the case when the policies are learned from big data.

We recognize there is a small price to pay for our “elicit a step if not articulated by the student” policy. After all, high-knowledge students may be annoyed by the fact that they have to articulate all steps and justify them. We believe the payoff is worth this risk in our first implementation of DeepTutor. We do intend to explore different policies in the future. To some extent, we already experimented with a new policy that mitigates this risk, specifically by skipping some of the steps that we are confident many students already master. For instance, solutions to particular problems aligned with higher levels of understanding in the LP have specific steps being optional (students will get credit if articulated but the system will not elicit these steps). The way we implemented the policy required effort at authoring time because solutions to problems aligned with a higher level of understanding in the LP needed to be proactively authored in ways to support the implementation of this policy at tutoring time. There is one strong reason for which we made this choice of shifting parts of implementing this policy at authoring time: to maintain the logical coherence of the solution and dialogue. Doing it entirely dynamically is a very complex task, which we explicitly avoided to tackle (for now). Indeed, maintaining the coherence of the dialogue and of the solution itself is a very complex task. If some steps of the solution are dynamically skipped, there is a high risk of ending up with a broken dialogue and incoherent solution with undesirable effects on learning. It should be noted that our current implementation of this tactic (using VanLehn and colleagues’ meaning of tactic) does not account, for instance, for other factors such as students’ affective state or motivation. We do plan to add strategies, policies, and tactics that address learners’ affect and motivation.

Due to space reasons, we do not elaborate on the other VanLehn and colleagues tactics’ implementation in DeepTutor. We would like to add that one advantage of DeepTutor over the system described by VanLehn, Jordan, and Litman (2007) is macro-level adaptation, i.e., the selection of instructional tasks based on students’ background. Macro-level adaptation implies the need for macro-level strategies and tactics to address issues such as instructional task selection and sequencing (see Rus et al., 2013a). Furthermore, it should be noted that DeepTutor addresses conceptual physics, while the system described by VanLehn, Jordan, and Litman (2007) includes quantitative problem solving accompanied by conceptual explanations. These differences may further explain the different instantiations of the strategies and four tactics in VanLehn and colleagues’ paper.

Collins, Brown, and Newman (1987) present three previously studied “pedagogical methods:” reciprocal teaching, procedural facilitation, and teaching problem solving. Their analysis led to a framework for guiding the design of learning environments. The framework itself includes six teaching methods: modeling, coaching, scaffolding, articulation, reflection, and exploration. Interestingly, the teaching method of coaching involves observing students and offering “hints, scaffolding, feedback, modeling.” They also mention “heuristic strategies” that are rules of thumb for how to approach a problem. One such rule specifies how to distinguish special cases in solving math problems. It seems to us that their heuristic strategies may be equivalent to tactics in GIFT due to their domain specificity. Problem-solving strategies and the control strategies (how to select among problem-solving strategies) are part of the content dimension of their framework. The framework includes three other dimensions: method (which includes the six teaching methods mentioned above), sequencing, and sociology. An interesting remark that offers support for our hierarchical dendrogram model is the fact that the control strategies “operate at many different levels”, e.g., across domain problem-solving strategies or more domain-specific heuristics and strategies.

In conclusion of this brief literature review, we remark that one major difference among the various works cited above is the level of granularity at which instruction is analyzed, and consequently, the strategies and tactics defined. Indeed, there are strategies at course level (Rothwell & Kazanas, 1998), lesson level (Rothwell & Kazanas, 1998), activity level (VanLehn, Jordan & Litman, 2007), and step level (VanLehn, Jordan & Litman, 2007). We define our dendrogram model based on these (and some other) levels of instruction granularity. This allows us to preserve the many usages of the terms strategies and tactics, as exemplified by the above literature.

Dendrogram Model of Instruction

Based on the previous overview of the various conceptualizations of strategies and tactics, we propose a framework to unify them. The framework is based on the observation that various researchers and communities define strategies and tactics at different levels of granularity. Furthermore, because different researchers use different terms such as principle, approach, method, strategy, tactics, and so on, we propose to use just two terms, strategies and tactics, for all levels of granularity. The alternative would be to use a larger set of terms, each attached to a specific level of instruction granularity. For instance, we can talk about instructional methods at course level, about strategies at lesson level, and tactics at solution level. The difference between using the shorter or larger set of terms is not conceptually important as the emphasis in both cases is the same: identifying strategies (or being called principles or methods or else) that shape the types, frequency, and sequence of activities as well as the delivery format (overall called plan of action). The tactics would be the activities or local decision regarding the activities (which result in actions) included in the resulting plan.

As already mentioned, our proposed framework defines strategies and tactics at different levels of instruction granularity. For instance, following Rothwell and Kazanas (1998), there is a course level of instruction as well as a lesson level. Strategies at course level are about organizing (choose topics, their frequency/repetition-rate, and sequence them) the sessions/lessons in a whole course. Examples of such strategies are strategies based on LPs (as in DeepTutor) or strategies based on topic prerequisite structure. At the lesson level, the strategies indicate how to choose the type and frequency of activities and sequence them within a single lesson, e.g., following a guided inquiry based instructional strategy (another typical strategy at this level is variable practice which entails presenting the target concepts in different contexts). The next level of instruction granularity is activity (within or associated with a lesson). A typical activity within a lesson is problem solving, i.e., applying learned concepts through problem solving, which is the standard activity in DeepTutor (Rus et al., 2013a) or the tutor described by VanLehn, Jordan & Litman (2007). In DeepTutor, there is an outer-loop that manages the problem-solving activity at a macro level and which is responsible for choosing the problems and sequencing them appropriately. Once a problem is selected, then DeepTutor selects the steps of the solution (this is called the solution level of instruction granularity). Specific strategies and tactics can be defined at this level (VanLehn, Jordan & Litman, 2007). Furthermore, in DeepTutor, there is a sequence of hints associate with each step in the solution to a problem. DeepTutor uses a relatively complex mechanism to choose the type and best sequence of hints to give students in order to help them articulate the step by themselves. There could be strategies and tactics defined at this step level as well. The solution and step levels of instruction granularity in DeepTutor correspond to VanLehn's (2006) inner-loop although in our case the solution and step levels of instruction are implemented as two nested loops. The inner loop in VanLehn (2006) two-loop framework manages the student-system interaction while the student works on a particular task, e.g., a solving a physics problem. The outer-loop in VanLehn's framework selects the next task for the student to work on. In summary, based on the above analysis of our own work and others' work we can talk about strategies and tactics at course level, lesson level, activity level, solution level, and step level.

There is one extra level above course, which we call standard/curriculum level of instruction, which is meant to create a plan for covering a target domain across grade levels. Strategies at this level shape the major topics and their sequencing across grade levels. A typical strategy at this level would be based on LPs that map the instruction of big ideas in a domain across grade levels. Other strategies would be to use the prerequisite structure or recommendations from experts. One could argue for yet another level, the grade level. Strategies at grade level shape the mixture and sequences of courses within a grade. For instance, an Introduction to Physics course should be taught in fall and an Advanced Physics course in spring. Figure 1 offers a simple view of the hierarchical levels of instruction, which can be associated with specific strategies and tactics.

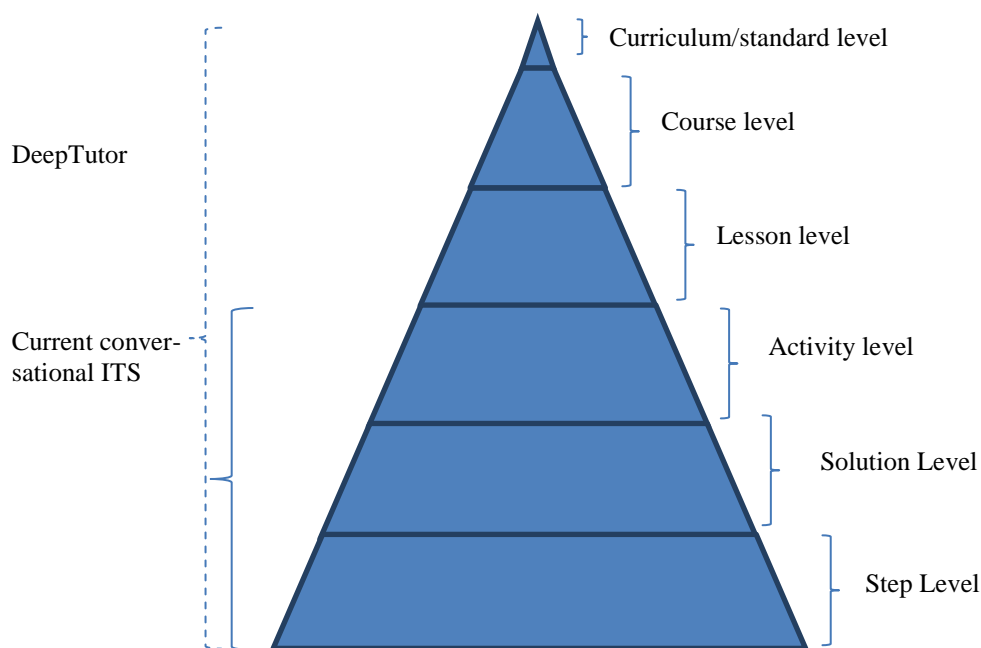


Figure 1. Simplified view of the hierarchical dendrogram model of instruction.

Figure 2 shows a more detailed view of the proposed general model of instruction, which takes the shape of a dendrogram, an hierarchical structure used in data clustering to show the relationship among clusters of various granularities. We show at each level the major activities that are included in the plan at that level, which is, in turn, shaped by the corresponding strategies. For instance, at the lesson level, the strategies will shape the lesson plan, which means choosing the type, frequency, and sequencing of activities within a lesson. Note that the lesson plan includes types of activities, frequency, and an actual sequence of activities. The same strategy can result in different mixtures of types (activity 1, activity 2 - Problem Solving, activity 3), frequencies (30%-40%-30% mixture of activity 1, activity 2, and activity 3, respectively), and sequencing. The different mixtures are the result of applying different tactics during actual instruction. The tactics thus make local decisions (e.g., trigger a deep question next or not) based on dynamic aspects of the learning environment and student background and input. The strategy imposes constraints on the type of tactical decisions thus determining the space of possible plans/mixtures. A particular sequencing that is chosen for a particular student or groups of students with same characteristics during one session is a policy. In general, a policy is a strategy with a bias. A policy can be defined by the developer, determined at training time, or learned, e.g., through data mining of reinforcement learning.

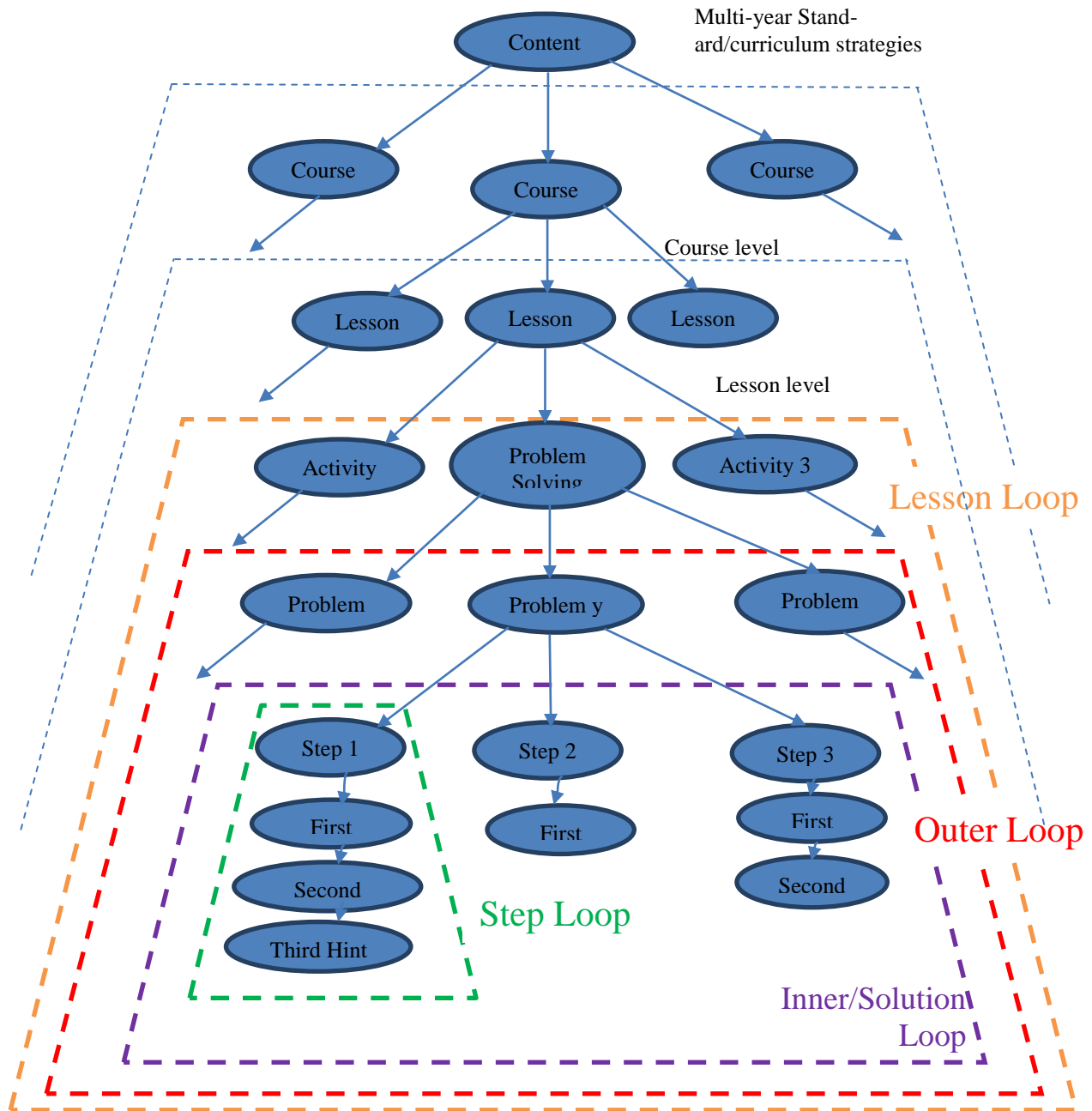


Figure 2. Detailed view of the dendrogram model of instruction illustrating the various levels of instruction granularity, the major activities/actions, and strategies.

The three concepts of strategy, policy, and tactics can be applied to all levels of instruction granularity. For instance, when creating a lesson plan, a teacher may use a guided inquiry instructional strategy to generate the plan, which means specifying the activities, frequency, and their sequence. During actual instruction she may use tactics to adjust the plan based on the dynamics of the classroom resulting in an enacted lesson plan (Gunckel, 2008). There is a variety of possible enacted lesson plans and the guided inquiry strategy delimits the space to a subset. That is, the strategy defines possible plans while during actual instruction through tactics and based on the dynamics of the learning environment, including student responses, an actual plan will be enacted. The actual plan will be known only once the class is over. Sometimes, the bias in the plan is clear and known. For instance, an “self-explanation” strategy that

is biased toward “an always ask for an explanation” policy. That is, the bias in the strategy is generated from (pre-)setting certain tactical decisions, leading to a policy. The policy can be also dynamically obtained, e.g., through reinforcement learning, which often may result in a policy without a clear interpretation of its bias (explained next); this is also the case when the policies are learned from big data.

We analyze now how these three concepts (strategy, policy, and tactic) apply at the activity level based on the design in VanLehn, Jordan, and Litman (2007). According to VanLehn, Jordan, and Litman (2007), they learn a “strategy” (at solution level according to our dendrogram) from data. The strategy is grounded on the modeling-scaffolding-fading “theory.” It should be noted that these learned strategies are anonymous as there is no clear meaningful interpretation for each learned sequence of “elicit-or-not” and “explain-or-not” actions. In fact, it would be hard to find a label for each mixture of long sequences of the two tactics as the space of possibly mixtures is large. Using our strategy-policy-tactic concepts, we can regard their design as involving one strategy (modeling-scaffolding-fading) that defines the set of possible mixture of tactics. A particular mixture of tactics is a policy (learned from data in their case) that may bias the overall plan (all the actual actions taken by the tutor during the solving of one problem) in one way or another. For instance, at one extreme, a resulting policy would be to always elicit, while at the other extreme, it would be to always tell. Yet another policy would be “elicit a step if not articulated by the student” and “tell”, i.e., articulate the step to make sure it is in the common ground of the conversation. This is the current policy in DeepTutor at the problem-solving/activity level. The policy is more sophisticated as we have step types. For instance, we have optional steps, which are steps that are not necessary for a good solution to a problem but which, if articulated, need be acknowledged. It should be noted that when eliciting a step from the student, DeepTutor offers appropriate scaffolding, as needed, to help the student articulate the missing step. The scaffolding is done using a constructivist strategy that encourages students to articulate the step by themselves. Help is offered only when the student struggles. Sequences of progressing hints are available for each step in the problem that provide less information initially (more vague hints) and then progressively more information, depending on the particular student. The strategy at this step level is more complex than that. For instance, we have conditional hints, which will only be triggered when certain conditions are met. Other strategies to scaffold the articulation of a step in the solution to the physics problem could be used.

In the dendrogram model in Figure 2, strategies at higher levels impact the strategies and tactics or the implementation of strategies at lower levels. For instance, a guided inquiry-based strategy for generating lesson plans at the lesson level would entail certain types of strategies, policies, and tactics at lower levels and exclude others such as lecturing. Certain activities in a plan entail their own specific strategies. For instance, there is a general problem-solving strategy that can be summarized as follows: 1) read and understand the problem carefully, 2) identify the given and unknown variables, 3) generate a strategy to find the unknown variables based on what is given and also based on world and domain knowledge, and 4) execute the strategy to find the unknown variables in order to solve the problem.

A question arises with respect to what levels in the dendrogram ITS developers should worry about. The answer differs depending on the perspective: current state of the art versus long-term vision. Current ITSS mainly address the problem-solving activity level, solution level, and step level. Early attempts to dynamically address the course/standards and lesson levels were made during the design of DeepTutor. Indeed, because DeepTutor relies on LPs, which track big ideas related to a target domain across grade-levels, we can claim that DeepTutor covers all levels (our LPs are aligned with curriculum standards). Addressing all the instruction levels in our dendrogram model will allow future educational technologies to serve three major types of users: 1) aspirational users whose learning needs are expressed as professional goals (“I would like to become an electrician”), 2) conscious learners who are aware of their need-for-improvement with respect to a topic (their needs are expressed in the form “I would like to learn more about Newtonian physics”) and 3) focused learners who have a specific learning need, e.g., need help with solving a concrete problem whose solution is due tomorrow. A one-stop-shop educational portal,

e.g., with a simple interface à la Google where learners simply type their needs, would handle these three types of users differently by directing them to educational technologies that implement strategies at different levels of granularity. For instance, aspirational users would be directed to a computer tutor that implements curriculum and standards-level strategies that will be able to generate a study/degree plan based on student's background. The study plan will include a list of courses in an appropriate sequence. Once the degree plan has been generated, the student will be directed to specific computer tutors that handle the course level of instruction. Current ITSs can handle mostly the conscious learners. Human tutoring services such as Tutor.com can handle the third type of users as current ITSs are not yet ready to help students with "surprise" problems, which are problems unknown a priori to the computer tutor.

Instructional Strategies in DeepTutor

DeepTutor (Rus et al., 2013a; Rus et al., 2013b) is the first ITS based on the framework of LPs (Duschl, Maeng & Sezen, 2011). LPs organize a target domain from a learner's perspective and the basic idea is to map out successful learning trajectories that students follow from naïve conceptions to mastery. The LPs are modeled as a set of hierarchical levels of understanding which increase in sophistication the higher up in the hierarchy they are. We define an instructional trajectory as a sequence of instructional tasks that students are engaged in and which are meant to help students develop sophisticated conceptualizations of the target domain, i.e., move up the LP hierarchy.

We distinguish in DeepTutor (Rus et al. 2013a) among strategies that are appropriate at the macro level, i.e., strategies that help decide the type and sequencing of instructional tasks a student is supposed to work on during a single training session or across many sessions, and at the micro level, which are strategies that impact the interaction between the learner and DeepTutor within a task, e.g., while solving a particular problem. Examples of macro-level strategies are anchored learning and spacing. They correspond to the lesson level in our dendrogram model of instruction. Examples of micro-level strategies are question asking and feedback. These strategies correspond to the solution and step levels, which together correspond to the inner-loop in VanLehn's two-loop framework. DeepTutor includes macro-level strategies corresponding to the activity level and above (e.g., LPs can be viewed to span many sessions, i.e., the course level, many courses – grade level and grades – curriculum standard levels) in the dendrogram model while the micro-strategies correspond to the solution level and below. Using VanLehn's (2006) two-loop framework for describing the functionality of ITSs, the macro-strategies control the outer loop of a typical ITS and the micro-strategies shape the inner loop. As the dendrogram shows, there are strategies at the step level also that control the atomic or sub-step loop, which in DeepTutor consists of sequences of hints that have types and are dynamically sequenced. Generally speaking, there is one constructivist scaffolding strategy at the atomic or sub-step loop: help students articulate the step by providing minimal information, i.e., only as much as students need to articulate the answer by themselves. There is a quite sophisticated mechanism to guide the step-level scaffolding, e.g., hints have types and are dynamically sequenced based on the student model while maintaining the coherence of the solution to the problem and dialogue.

We paid special attention to one level of instruction granularity in DeepTutor: course level. Because we have designed and integrated in DeepTutor as a LP for Newtonian physics, DeepTutor is able to sequence the topics in a course on Newtonian physics across many sessions. In other words, there is a course-level loop in DeepTutor. However, the nature of the interaction between the suggested domain map in the LP and the activity of problem solving is not yet fully understood and therefore the advantages of disadvantages of various course-level strategies are not yet fully known. As of this writing, we have experimented with two course-level strategies: 1) a drilling/depth strategy in which over multiple sessions of DeepTutor-student interaction students are drilled on a major topic per session, e.g., Newton's third law, and 2) a breadth strategy, which was used in one-session experiment; the idea was to remediate the

weakest aspects of students' knowledge across all Newtonian physics topics in one session. Our Newtonian physics LP (Rus et al., 2013a; Rus et al., 2013c) includes seven strands corresponding to seven major topics in Newtonian physics LP such as Newton's first law, Newton's second law, free-fall, etc.

DeepTutor implements a number of strategies including scaffolding through constructivist dialogue, modeling-scaffolding-fading, multiple representations with explanation and coordination, self-explanation, deep questions, modeling (summarization, asking questions), anchored instruction, variable practice, feedback, assessment, interleaving topics versus drilling (constraint by experimental setup), worked-out examples, and contrastive cases. A general problem-solving strategy is also implemented in DeepTutor because the major activity is problem solving. Domain-specific tactics are used to implement the strategy while generating specific solutions to specific problems. These tactics are primarily enacted at authoring time by experts who generate the solutions to the problems. DeepTutor simply and dynamically reenacts the problem-solving strategy encoded in the solution at tutoring time.

The bottom line is that the actions that DeepTutor takes and that are directly observed by students are the result of many strategies that are simultaneously active. In general, we can say that the actual moves taken by a tutor (human or computer-based) are the result of many strategies addressing the various aspects of learning (socio-cognitive-affective-motivational) under various constraints from environment such as technological, modality inspired, and pragmatic. When exposed to actions that are the result of many strategies, students must decode the actions that they directly perceive in ways that tutors hope would have the best impact on learning. Therefore, it is tutors' job to best select and mix the strategies in ways that students' decoding is most successful from a learning perspective.

To best model this strategy composition and decoding process, we propose a Fourier transform model inspired from Fourier analysis in mathematics according to which a general function can be decomposed into the sum of basic trigonometric functions. The sum of all the functions (see Figure 3) results in the complex function, which in our tutoring context corresponds to the moves the tutor actually makes and which the student directly perceives. That is, a tutor does a Fourier synthesis during tutoring, which consists of summing up the effects of individual strategies. In fact, the tutor may do more than just a sum operation because the process of combining strategies is yet to be understood.

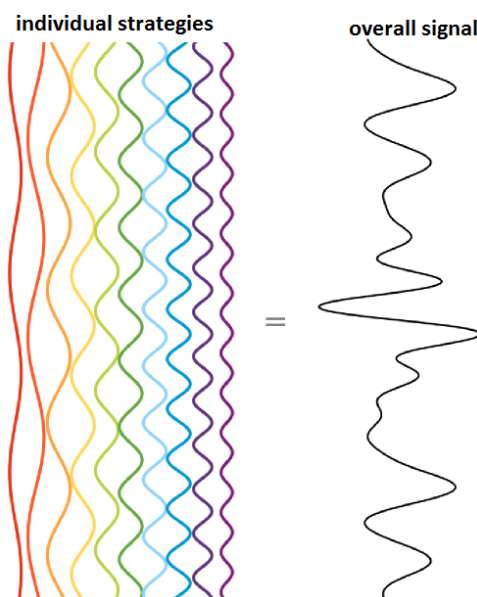


Figure 3. The resulting wave corresponds to a tutor move that the student perceives and is the sum (meaning a complex way of combining) of individual waves that correspond to different strategies and tactics.

As already mentioned, a critical step in our Fourier model of tutor actions is combining the effect of many activated strategies resulting in a specific tutor move, which the student then perceives. We present next two ways to approach this composition of strategies problem: assembly of binary decision processes or a more elaborate process. In the first approach, we assume that at each moment all strategies will be inspected and a decision be made whether to activate or not activate the strategy (a binary decision). Once all the activated strategies are available, a composition step that combines the effect of all the active strategies into one or more actions would follow. The composition could be simple, i.e., a simple concatenation of effects/actions or complex. For instance, the activation of a “coordination of representations” strategy and “induce confusion” strategy could be implemented as a dialogue move through a concatenation of two sentences: one for the “coordination of representations” (“Look at the image.”) and a contradictory statement meant to induce a state of confusion (“The large truck exerts a larger force on the small car” – confusion has been shown to help learning [D’Mello, Lehman, Pekrun & Graesser, in press]). Alternatively, the composition could aim at generating more naturalistic dialogue moves that combine the effects of the two strategies into one sentence: “As shown in the image, the large truck exerts a larger force on the small car.” While this type of response is more natural and preferable, the underlying composition process is complex. As expected, the complexity increases significantly when more than two strategies must be accounted for.

The other approach, the elaborate process, would be to learn a function that maps the set of strategies into the desired outcome directly. For instance, the learned strategies activation function will simply generate the naturalistic response (“as shown in the image, the large truck exerts a larger force on the small car”) in a context in which the right factors would justify such a response (and assuming the function was successfully learned). There is no explicit way to treat separately the two strategies whose effects are embedded in the above response.

We would like to add that the opposite process of observing the actions of a tutor and finding its individual strategies would be equivalent to a Fourier analysis of the synthesized tutor response. The synthesized tutor response (see the overall signal to the right of Figure 3) that embeds/hides the effects of many strategies and is sent over a noisy channel. That is, what the student actually perceives would be a noisy version of the synthesized response. The role of the instructor is to generate the right signal that best “resonates” with the student. That is, the synthesized signal should be such that it makes it easier for the student to decode it in ways that enable a triggering of effective learning processes.

Recommendations and Future Research

In conclusion, we would like to make several points. First, there is a range of understandings for strategies and tactics in the education-at-large literature. One major difference among the various papers we discussed is the level of granularity at which instruction is analyzed, and consequently, the strategies and tactics defined. We defined a dendrogram model of instruction based on various levels of instruction granularity, which allowed us to account for the many different usages of the terms strategies and tactics. At one extreme, we can claim there is only one strategy in tutoring as observed from the highest level of instruction granularity: maintaining the learner in “the zone” (of proximal development). On the other hand, the actions taken by a tutor can be viewed as the result of many strategies that simultaneously shape these actions. This view is captured in our Fourier analysis model of instruction actions.

Second, based on the terminological disparity among various research groups and communities, there is a need to standardize the use of terminology. The GIFT project is pushing for this unification and our proposal is meant to help in this effort.

Third, many strategies at the same level of granularity seem to overlap or be dependent on each other. An analysis of these commonalities, differences, and interdependencies is needed. For instance, there is an intrinsic interdependency between the strategies of asking questions and guided self-explanations or between asking questions and scaffolding in conversational tutors. Similarly, for instance, Collins, Brown, and Newman (1987) define coaching as being dependent on modeling and scaffolding.

Fourth, some strategies must be re(de)defined. For example, self-explanation is not an instructional strategy but rather a learning strategy (what the learner does). The instructional strategy would be “encouraging, maintaining, and increasing self-explanation behavior.” As a general rule of thumb, one could say that any learning strategy can be transformed into an instructional strategy by way of the tutor “encouraging, maintaining, and increasing” student’s use of a particular learning strategy.

Fifth, there are other aspects of tutoring that impose their own strategies or constraints on the implementation of core cognitive strategies, such as the ones discussed earlier. Pragmatic aspects impose the use of strategies to, for instance, mitigate gaming-the-system behavior. Modality and technological constraints shape the implementation of strategies. We already mentioned the need to maintain the logical coherence of the solution and of the dialogue in conversational tutoring systems. The role of the instruction delivery method is indeed important (Anderson, 1983). Similarly, technological constraints have an impact on the type of strategies or their implementation. For instance, in dialogue-based ITSs, the assessment of students’ utterances rely on NLP techniques. Although much progress has been made in the area of NLP, the current state-of-the-art algorithms are not perfectly accurate. Due to this limitation, in DeepTutor, we have implemented a strategy that avoids one of the worst situations in tutoring, which is giving negative feedback when the student is right. This typically results from a false negative generated from the assessment module in DeepTutor because of limitations of the NLP technology. That is, due to these technological limitations sometimes a student response is deemed incorrect even though it is correct. The opposite is also true: sometimes an incorrect response is deemed correct by using state-of-the-art automated NLP algorithms. However, this situation is less harmful because even if the system believes the student is right when the student is not, it provides positive feedback and then asserts the correct answer (which would be different from students’ incorrect answer). The bottom line is that in this case the student will eventually see the correct response. The former case is worse because high knowledge students know when they are right and getting negative feedback disengages them, sometimes to the point of losing confidence in the system or, in the worst-case scenario, even quitting using the system. Because we believe the false negatives are worse, we adopted a policy (strategy with a clear bias) that tends to give students the benefit of doubt when the assessment module is less confident. That is, our policy is to give positive feedback when student’s response is close to being correct but not sure.

Sixth, strategies that address other aspects of learning, such as affect and motivation, must be considered and their interaction with the major cognitive (targeting processing of content) strategies discussed in the context of GIFT. Similarly, strategies targeting social aspects must be addressed as well. Social strategies, e.g., strategies that modulate the dialogue interaction between the tutor and student, are inherent in our dialogue-based computer tutor DeepTutor. We also have strategies that encourage verbosity or whose goal is perfect grounding at every turn. Furthermore, it could be argued that the providing feedback strategy is by itself touching upon affect and motivational aspects of learning. For instance, a negative feedback in response to an incorrect student statement would clearly impact students’ affective and even motivational state.

Another view of strategies, in accordance with the dual (if not multiple) view of strategies similar to (Rothwell and Kazanas, 1998), would be that strategies are general and that implementing them requires specifying their social, cognitive, affective, and motivational effects. In other words, the implementation of a strategy must indicate its social, cognitive, affective, and motivational impact. Some strategies may have limited or no impact on one or more of these dimensions. One can also argue that the way a strategy

is implemented (through a policy), not its core intent, will impact more or less a dimension of learning. For instance, the form of positive feedback can have more or less of an impact on learner's motivation. Indeed, the following three different forms of implementing positive feedback "Good" vs. "Outstanding answer" versus "Perfect answer that is way above your peers" could have different degrees of motivational impact. We plan to further explore this idea of describing each strategy based on their impact on the four main dimensions of learning.

We would like to end with noting that understanding the role of strategies, policies, and tactics in ITSs is a complex issue that is yet to be fully understood. We hope this chapter will help with making progress toward this goal and, in particular, will help with the conceptualization and implementation of strategies and tactics in GIFT (Sottolare et al., 2012).

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