

Appendix 1: Teaching Strategies

We describe each of the thirteen teaching strategies implemented in the pedagogical module. There can be more than one teaching strategy in an intervention.

Strategy 1: Remind the student about the information relevant to making a decision (Stage: preoperative)

SDMentor points out the relevant information for making a choice when a student fails to identify the correct action details in the question from strategy 9 in the preoperative stage.

Preoperative situation: A student reported a treatment plan for the premolar tooth number 34.

SDMentor: To insert the rubber dam, what is the appropriate clamp number? (Strategy 9)

Student: (incorrectly answers the first time)

SDMentor: Don't forget that the clamp size is related to the working tooth type.

To generate content, the correct AC node (AC:TOOTH_TYPE=PREMOLAR && CLAMP_NO=2, node 2) from strategy 9 (Fig. 10) is selected. The CLAMP_NO and TOOTH_TYPE are mentioned in the hint.

Strategy 2: Provide a hint (Stage: intraoperative)

SDMentor gives a hint to encourage the student to perform an action that conforms to the correct plan. When a student performs an action that does not follow the correct plan (procedural error), SDMentor generates a hint.

Intraoperative situation (2.1): The planned action is to insert a rubber dam; this action is in the middle of the procedure; the student selects a round diamond bur instead of inserting a rubber dam.

SDMentor: Think about an action required to make the working tooth is isolated from the oral environment.

Intraoperative situation (2.2): The planned action is to provide local anesthesia. The student inserts a rubber dam instead of picking up the local anesthesia needle.

SDMentor: Think about an action required to make the working tooth is entirely numb.

Intraoperative situation (2.3): The planned action is to drill to open access by using the steel round bur. Now, the dentine layer of the working tooth appears, and the student is holding the round diamond bur — the student drills to the pulp chamber using (the same drill).

SDMentor: Think about an action required prior to make the pulp chamber floor appear.

The pedagogical module generally uses the main outcome of the correct action to generate a hint (situation 2.1). Depending on the sequence of the actions expected to be performed in the whole procedure, if the planned action is the first action in the procedure, e.g., picking up the local anesthesia needle in a subplan of providing local anesthesia, the desired outcome of the subplan, which is working tooth is numb, is used for generating a hint (situation 2.2). If the planned action is an action that does not have immediate effects, e.g., `select_bur_to_open_access` (Fig. 7), the pedagogical module searches for the affected action (`drill_to_open_access`) and picks its primary desired outcome (`PULP_CHAMBER_FLOOR_VISIBLE`) to generate a hint (situation 2.3).

Strategy 3: Point to the unusual situation (Stage: intraoperative)

SDMentor provides the student with a learning opportunity for dealing with an unusual situation. This situation is an error from the executed action. The student must recover it.

Intraoperative situation: The student drills to open access to the pulp chamber floor; profuse bleeding occurs.
SDMentor: Look! The pulp chamber floor has profuse bleeding.

The conditional action in the surgical procedural graph is used for generating this. When the next action to be performed is conditional, the pedagogical module checks whether the condition of the next action to be performed is satisfied. The condition is used as part of the message. For example, according to Fig. 13, when the student drills to open access to profuse bleeding, the projected effect (PJ: PULP_CHAMBER_BLEEDING_PROFUSELY, node 1), which becomes part of a situation (P, node 2), is used to run through the domain rules for the additional meaning of the current fact (C: PULP_CHAMBER_FLOOR_PERFORATED, node 3). This derived information satisfies the condition of the child action (stop_bleeding, node 4).

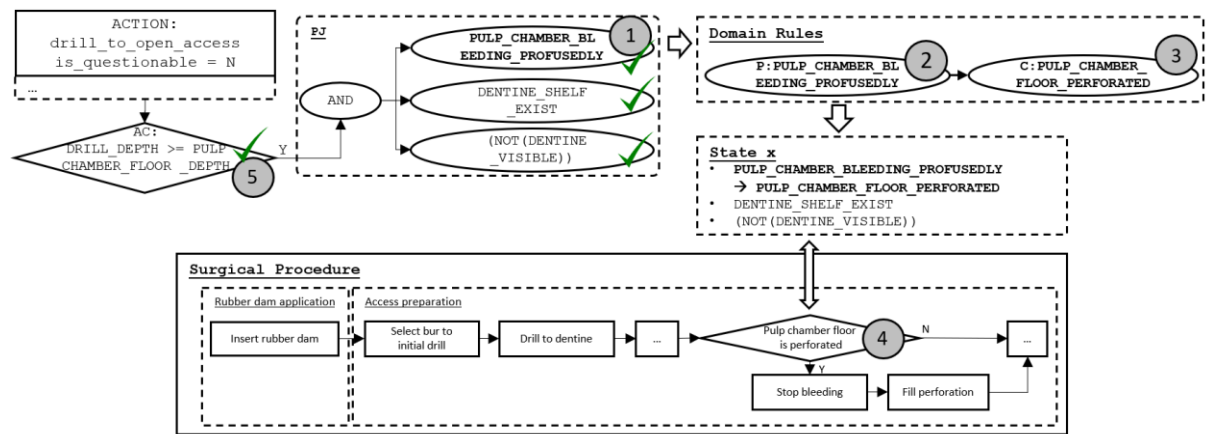


Fig. 13 A process of how the pedagogical module deals with a conditional action

Strategy 4: Direction (Stage: intraoperative)

SDMentor directs the student to perform an action. This directive is given when a student either must fix an error (situation 4.1) or makes a procedural error repetitively (situation 4.2).

Intraoperative situation 4.1: The profuse bleeding occurs after opening the access.	
SDMentor: Look! The pulp chamber floor has profuse bleeding. (Strategy 3) Why? (Strategy 13).	
Student: (correctly answers)	Student: (incorrectly answers)
SDMentor: That's right. (Strategy 5)	SDMentor: I don't think it's right. (Strategy 6.1) The answer is the drilling depth is greater or equal to the depth of the pulp chamber floor. (Strategy 7)
SDMentor: You have to stop the bleeding and fill the perforated pulp chamber floor.	

Intraoperative situation 4.2: The rubber dam is not inserted; a student selects a round diamond bur instead of inserting a rubber dam (for the second time).
SDMentor: Select a bur for initial drilling.

The pedagogical module uses relevant action details to generate a direction when the student acts incorrectly (situation 4.3), and the action is not suitable for asking a question. The content of the direction is the action details to which attention needs to be paid. A direction is generated after the negative feedback (Strategy 6.2).

Intraoperative situation 4.3: The student selects a round diamond bur and drills to the dentine using a bur size that is larger than the pulp chamber width. The drilling action is not appropriate for asking a question.

SDMentor: The working tooth is overcut. (Strategy 6.2)

SDMentor: Check the bur size and the pulp chamber width.

Using the graph in Fig. 9, the pedagogical module selects the incorrect outcome (PJ: STRUCTURE_ OVERCUT, node 17) from the student solution graph and traces back to its parent (AC: DRILL_ SIZE>PULP_CHAMBER_WIDTH, node 16) containing action details. The variable names of the action detail, DRILL_SIZE and PULP_CHAMBER_WIDTH, are employed to generate a direction.

Strategy 5: Positive feedback (Stage: preoperative, intraoperative)

Positive feedback is given to inform a student of a correctly performed action or a correct answer to a question.

Pre/Intraoperative situation: SDMentor asks a question.

SDMentor: Why do you provide local anesthesia?

Student: (correctly answers)

SDMentor: Good.

Strategy 6: Negative feedback

SDMentor gives negative feedback to inform the student if the decision is not correct. There are two types of negative feedback.

Strategy 6.1: Short negative feedback (Stage: preoperative, intraoperative)

When the student answers a question incorrectly, SDMentor gives short negative feedback.

Pre/Intraoperative situation: In the preoperative stage, SDMentor asks for the plan details about using the appropriate clamp number to insert a rubber dam. The student answers with the appropriate clamp number.

SDMentor: Why? **Student:** (incorrectly answers)

SDMentor: That is not right.

Strategy 6.2: Informative negative feedback (Stage: intraoperative)

SDMentor informs the student of the incorrect outcome as negative feedback when the student incorrectly performs a surgical action in the intraoperative stage. This is to implicitly tell the student to try again.

Intraoperative situation: A student inserts a rubber dam with the clamp no 9 for the premolar 34.

SDMentor: The rubber dam with the clamp is not successfully inserted into the working tooth. And the working tooth is not isolated from the oral environment.

Consider the graph shown in Fig. 10. When a student inserts a clamp number 9 to a premolar, the PJ nodes (PJ:NOT CLAMP_INSERT, node 5; PJ:NOT TOOTH_SEPARATE, node 6) and AC node (AC: TOOTH_TYPE=PREMOLAR && CLAMP_NO=9, node 7) are checked as the student solution graph. The pedagogical module traces the student solution graph for undesired outcomes (PJ) corresponding to the incorrectly performed action. The PJ nodes (node 5,6) become part of the negative feedback.

Strategy 7: Tell the answer (Stage: preoperative, intraoperative)

SDMentor tells the answer after the student fails to provide the rationale behind a decision. In the preoperative stage, it does not tell the answer until the end of discussing the topic.

Preoperative situation: A student proposes a treatment plan.	
SDMentor: Why do you provide local anesthesia? (Strategy 10.3).	Student: (incorrectly answers)
SDMentor: What is the patient's diagnosis? (Strategy 11.1)	Student: (incorrectly answers)
SDMentor: What does pulpitis mean? (Strategy 11.2)	Student: (incorrectly answers)
SDMentor: Diagnosis is pulpitis, and the pulp is vital.	

SDMentor tells the answer in the intraoperative stage at an earlier point than in the preoperative stage because this is the period when a student provides actual treatment to the patient. When the student fails to answer a question, SDMentor immediately tells the answer.

Intraoperative situation: After providing local anesthesia to the patient, a student inserts a rubber dam to a premolar with the incorrect clamp number.	
SDMentor: The rubber dam with the clamp is not successfully inserted into the working tooth. And the working tooth is not isolated from the oral environment. (Strategy 6.2) Check the clamp number. (Strategy 4.2) What should be the correct clamp number? (Strategy 9)	
Student: (incorrectly answers)	
SDMentor: The answer is clamp number 2.	

Strategy 8: Confirm the action (Stage: preoperative, intraoperative)

SDMentor confirms the action to be performed in the procedure as the ending remark of the discussion topic. In the preoperative discussion, it confirms the action necessary to be performed in the procedure. In the intraoperative discussion, when a student does not perform a task correctly, SDMentor asks a question about the correct action details to be performed.

Preoperative situation: SDMentor teaches about applying local anesthesia.	
SDMentor: Why do you provide local anesthesia? (Strategy 10.3)	Student: (incorrectly answers)
SDMentor: What is the patient's diagnosis? (Strategy 11.1)	Student: (incorrectly answers)
SDMentor: What does pulpitis mean? (Strategy 11.2)	Student: (incorrectly answers)
SDMentor: Diagnosis is pulpitis, and the pulp is vital. (Strategy 7)	
SDMentor: It is necessary to provide local anesthesia for a pulpitis patient.	

Intraoperative situation: When a student incorrectly performs an action, e.g., the student selects a round diamond bur, but the size is larger than the pulp chamber width.	
SDMentor: The bur size causes the working tooth to be overcut. (Strategy 6.2) Check the bur size and the pulp chamber width. (Strategy 4.2) What is the correct bur size? (Strategy 9)	
Student: (answers the question)	
SDMentor: That's right (Strategy 5 for the correct answer) OR That is not right (Strategy 6 for the incorrect answer)	
SDMentor: You should select the bur for initial drilling with a bur size that is less than the pulp chamber width.	

In the preoperative stage, when the necessity of the sub-plan is annotated (Fig. 6, :optional, la_plan), the condition (DIAGNOSIS NECROSIS) is evaluated to the initial situation (Fig. 5, :init). If the condition (DIAGNOSIS NECROSIS) does not satisfy the initial situation, the la_plan is mandatory to the procedure. The pedagogical module uses the sub-plan and its necessity as part of the message. In the intraoperative stage, the pedagogical module uses the student's incorrect action detail (DRILL_SIZE) as a key to search for the AC nodes of affected action (DRILL_TO_DENTINE) in the procedure. The affected action and the AC node (Fig. 9, the negation of node 17, DRILL_SIZE < PULP_CHAMBER_WIDTH)

having the child PJ node (Fig. 9, node 19) that satisfies the desired outcomes (NOT (STRUCTURE_OVERCUT)) are part of the message.

Strategy 9: Ask for the correct details of the action (Stage: preoperative, intraoperative)

This questioning strategy is applied in both the preoperative stage and the intraoperative stage. In the preoperative stage, SDMentor asks for the correct details of the planned action to verify the planned details. In the intraoperative stage, when a student performs a surgical task incorrectly, SDMentor asks this question after informing the student about an incorrect outcome and giving a hint.

Preoperative situation: A student reported a treatment plan for the premolar tooth number 34.
SDMentor: To insert the rubber dam, what is the appropriate clamp number? 1) Clamp number 2 2) Clamp number 14 3) Clamp number 9

The pedagogical module retrieves the domain graph of the action to be discussed (Fig. 10) and selects the PJ nodes containing the main desired outcome (node 1,3). It traces back to the parent AC nodes (nodes 2,4) and selects the one with the perceptual fact satisfied by the current state (node 2, tooth_type=premolar && clamp_no 2). The pedagogical module uses the action name (insert_rubber_dam) and the extracted user action detail (clamp_no) to generate the question. Choices are generated from the available values of the user action detail: 2, 9, 14.

Intraoperative situation: A student selects a round diamond bur (for initial drill) whose bur size is larger than the pulp chamber width.
SDMentor: The bur size causes the working tooth to be overcut. (Strategy 6.2) Think about the bur size and the pulp chamber width. (Strategy 4.2)
SDMentor: What is the correct bur size? 1) The bur size is greater than the pulp chamber width 2) The bur size is less than the pulp chamber width 3) The bur size is equal to the pulp chamber width

In the intraoperative stage, it is possible that the student incorrectly performs an action that does not have effects, e.g., (SELECT_BUR_TO_INITIAL_DRILL). The pedagogical module uses the performed action detail (DRILL_SIZE) to search for the AC nodes of affected action (DRILL_TO_DENTINE). The action detail in the AC node (Fig. 9, the negation of node 17, DRILL_SIZE < PULP_CHAMBER_WIDTH) having the child PJ node (Fig. 9, node 19) that satisfies the desired outcome (NOT (STRUCTURE_OVERCUT)) is the answer. The other similar AC nodes are choices.

Strategy 10: Confirm the rationale behind the decision (Stage: preoperative, intraoperative)

In order to ensure that the students are not just rote learning decisions and to help reduce the chances of students guessing the right answer, SDMentor queries the student to determine if s/he understands the rationale behind the decision. There are three sources of information to use in this respect: facts (Strategy 10.1), desired outcomes (Strategy 10.2), and conditions of the optional plan (Strategy 10.3).

Strategy 10.1: Confirm the fact related to the action details (Stage: preoperative)

SDMentor gives positive feedback after the student successfully identifies the plan action details from Strategy 9 or gives the correct answer if the student fails to do that twice. SDMentor asks a question to confirm that the student understands why the action is correct.

Preoperative situation: A student reported a treatment plan for the premolar tooth.	
SDMentor: To insert the rubber dam, what is the appropriate clamp number? (Strategy 9)	
Student: (correctly answers)	Student: (incorrectly answers for the second time)
SDMentor: That's right. (Strategy 5)	SDMentor: The answer is clamp number 2. (Strategy 7)
SDMentor: Why?	1) The working tooth is premolar. 2) The working tooth is molar. 3) The working tooth is anterior. 4) The working tooth is canine.

The pedagogical module generates a question using a fact relevant to the correct detail of the action. The correct AC (AC : TOOTH_TYPE=PREMOLAR && CLAMP_NO=2, Fig. 10, node 2) from Strategy 9 is selected. The value of the perceptual fact (P : TOOTH_TYPE) from the correct AC node is the answer. The other available possible values in the domain are used as choices.

Strategy 10.2: Confirm the objective of the performed action (Stage: Intraoperative)

When the student acts correctly, and it is appropriate to ask a question, SDMentor confirms the goal of the performed action.

Intraoperative situation: A student inserts the rubber dam correctly.
SDMentor: Why do you insert the rubber dam? 1) To isolate the working tooth from the oral environment 2) To open the working tooth to the oral environment

SDMentor uses the correct performed action as part of the question, and the main desired outcome of the action and its negation as choices. Some performed actions do not have immediate outcomes (e.g., `select_bur_to_initial_drill`). In this case, SDMentor uses the performed action details to search for the affected action with immediate effects. The main desired outcome of the affected action and its negation become choices.

Intraoperative situation: A student selects the round diamond bur with the correct bur size.
SDMentor: Why do you select the round diamond bur? 1) To maintain the dentine layer in future actions 2) To reveal the dentine layer in future actions

Strategy 10.3: Confirm the relevant condition of the optional plan (Stage: preoperative, intraoperative)

SDMentor asks a question to confirm the necessity of the plan when the action to be performed is part of the sub-plan that can be optional, e.g., `la_plan` (Fig. 6). If the student fails to answer this, SDMentor will ask the same question again in the intraoperative stage.

Preoperative situation: The proposed plan can be optional.
Intraoperative situation: In the preoperative stage, the student failed to answer the question of why providing local anesthesia is necessary. The student selected the local anesthesia syringe, which is the first action of the plan.
SDMentor: Why do you provide local anesthesia? 1) The patient has pulp necrosis 2) The patient has pulpitis

The pedagogical module uses the `la_plan` from the procedural graph as a question. It uses the variable of the optional condition (DIAGNOSIS) to search for available values in the

domain (PULPITIS and NECROSIS) to generate choices. The value satisfying the initial situation, PULPITIS, is the answer.

Strategy 11: Raise awareness of rationale behind the decision (Stage: preoperative, intraoperative)

SDMentor asks a question to make the student aware of the rationale behind a decision when the student fails to identify it correctly. The information to query is (1) the relevant perceptual fact, (2) its meaning, and (3) the future consequences.

Strategy 11.1: Raise awareness of relevant facts (Stage: preoperative, intraoperative)

SDMentor asks a question using relevant facts of the optional plan when the student fails to answer a question regarding the necessity of the sub-plan.

Pre/Intraoperative situation: The student fails to answer why providing local anesthesia is required.
SDMentor: Why do you provide local anesthesia? (Strategy 10.3) Student: (incorrectly answers)
SDMentor: What is the patient's diagnosis? 1) The patient has pulp necrosis 2) The patient has pulpitis

The pedagogical module uses the variable ‘DIAGNOSIS’ from the procedural graph as part of the question, and its available values NECROSIS and PULPITIS as choices. The choice satisfying the initial situation of the patient, PULPITIS, is the answer.

Strategy 11.2: Raise awareness of the meaning of the relevant facts (Stage: preoperative, intraoperative)

SDMentor knows that the student failed to recognize the information relevant to the decision; it asks a question about its meaning to raise awareness.

Pre/Intraoperative situation: The patient’s diagnosis is pulpitis. The student fails to answer the question, “What is the patient’s diagnosis?” (Strategy 11.1).
SDMentor: What does pulpitis mean? 1) The pulp is not vital 2) The pulp is vital

In this case, the pedagogical module traces the domain graph (Fig. 9) for the perceptual fact (P:DIAGNOSIS PULPITIS, node 13) to its comprehension node (C:PULP_VITAL, node 14). The value of the P node (PULPITIS) is part of the question. The C node, PULP_VITAL, and its negation, NOT (PULP_VITAL), become choices.

Strategy 11.3: Raise awareness about the future consequences (Stage: intraoperative)

Even though a student correctly performs an action, s/he may fail to identify why the action must be taken. SDMentor makes the student aware by asking about the future consequences.

Intraoperative situation: A student inserts the rubber dam correctly.
SDMentor: Why do you insert the rubber dam? (Strategy 10.2) Student: (incorrectly answers)
SDMentor: What can happen if you drill to the dentine layer when the working tooth is not isolated from the oral environment? 1) The pulp chamber floor is not visible 2) The patient cries out 3) The working tooth is overcut 4) Foreign objects like endodontic instruments or fluid can be easily dropped into the mouth

Consider the graph shown in Fig. 9. The pedagogical module negates the main desired outcome of the correct performed action (PJ:TOOTH_SEPARATED, node 10) as ‘NOT TOOTH_SEPARATED’ and uses it as a key to search for satisfying AC node

selects its parent (AC : DRILL_DEPTH>=PC_FLOOR_DEPTH, node 5) to be the answer. The similar AC nodes from the tutor graph become choices.

Appendix 2: Occurrence of Teaching Strategies

Table 8 Percentage of occurrence of teaching strategies by human instructors in the observational study and in the evaluation study

No.	Teaching strategy	Observational study	Evaluation study
1.	Remind the student about the information relevant to making a decision	6%	5%
2.	Provide a hint	3%	5%
3.	Point to the unusual situation	2%	1%
4.	Direction	11%	12%
5.	Positive feedback	3%	3%
6.	Negative feedback		
	6.1 Short negative feedback	2%	0%
	6.2 Informative negative feedback	3%	1%
7.	Tell the answer	3%	5%
8.	Confirm the action	6%	6%
9.	Ask for the correct details of the action	6%	1%
10.	Confirm the rationale behind the decision		
	10.1 Confirm the fact related to the action details	11%	12%
	10.2 Confirm the objective of the performed action	4%	4%
	10.3 Confirm the relevant condition of the optional plan	6%	7%
11.	Raise awareness of the rationale behind the decision		
	11.1 Raise awareness of the relevant facts	12%	14%
	11.2 Raise awareness of the meaning of the relevant facts	3%	4%
	11.3 Raise awareness of the future consequences	6%	6%
12.	Pose a hypothetical situation	9%	10%
13.	Inquire into the cause of the unusual situation	4%	5%