**Encouraging Reflection in the Physics Classroom**

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**Abstract**

High school students should be encouraged to reflect on their own learning. Reflection will enhance their metacognition and help them become the independent learners they will need to be in order to be successful in a university setting and in life. Such tools as described herein assist the physics teacher to encourage students to reflect. I present small group collaboration as an example of a tool for use in the specific mechanics topic of graphing position versus clock reading, to reinforce a reflective learning environment. I include what prior knowledge I expect students to have, difficulties related to reflection I expect to arise, and instructional strategies to overcome these difficulties. I relate the mechanics topic of graphing position versus clock reading to the NYS Physics Core Curriculum. I show how students can demonstrate an improved level of reflection after instruction by commenting on their own learning. The comments are instructor-plotted on a provided reflective learning scale.

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**Background**

 Reflection\* is an amazing human tool, capable of raising each of us to greater ability. According to Schön, “thinking [of] what they are doing while they are doing it,” called *reflection-in-action\**, leads to constructive insights (1987, p. 26-31). Reflection in general will focus attention on the factors involved in an action thus allowing one to remember the activity and judge it in respect to similar activities. Reflection on learning, specifically, will enhance a student’s metacognition\*, the awareness and knowledge of one’s own learning and the ability to communicate about one’s own learning (Metcalfe & Shimamura, 1994). Thus reflection will help him/her become an independent learner.

 The problem in education, as pointed out by Schön (1987), is that instruction communicates specific techniques but the choice of applying such techniques requires judgment in ethics. Problem-solving requires a wider understanding of the society and conditions in which the problem exists than specific techniques alone. Thus metacognition plays a role in deciding what factors are to be included in the problem to be solved. Of course, different professions have different roles, so it is to be expected that different people will choose a different set of factors to consider. However, it can be expected that a true professional will not solve a problem in a manner which will violate a law, or rights of people affected by his/her solution. More is required from education than familiarity with isolated facts; understanding of systems and ability to make inferences with new data is vital. Thus, independent learning skills are essential.

 It is increasingly true that new university students have graduated from secondary education without independent learning skills. These students, in great numbers, require remedial education in basic mathematics and English language arts. For the most part, such students are taking five or more years to complete a four year degree program. One challenge such students face is the vastly different environment. In high school, a student can expect to be told what is important to know and what it is and how it is used in each stated situation. For example, a formula is worked out by the teacher for each component as the unknown. If the given formula is “y = mx + b,” then the teacher expects to work out four examples, one for each component being unknown. In contrast, a university student must organize his/her own time, decide what is most important, study what he/she can of it and how this subset of a larger body of knowledge can be applied to varying situations. For example, the formula for gravitational potential energy is derived by the professor from more fundamental data. It is then the student’s responsibility to memorize the formula, learn the meaning of the components of the formula and how to apply the formula and under what circumstances it would be valid. Reflection would certainly help a student transition from a secondary to post-secondary setting if he/she knew how to study before hand. “The dean of a well-known school of management observed [around 1962] that ‘we need most to teach students how to make decisions under conditions of uncertainty, but this is just what we don’t know\* how to teach’ (William Pownes, personal communication, 1972).” (Schön, 1987, p. 11). A personal reflection of Carl Rogers to a group of teachers assembled at Harvard University in 1952 included the observation that the “only learning which significantly influences behavior is self-discovered, self-appropriated learning.” (Schön, 1987, p. 89). Reflection is a powerful tool in equipping students to be independent learners. Reflection is the bridge between knowledge and the uncertainty students will face.

 Reflective\* learning is an extensive process. The learning process consists of several steps. In all, the steps would include confronting a novel situation, recognizing the situation as novel, identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid. Confronting novel situations and recognizing the situation as novel is traditionally ignored in education. Efforts have been made by Tik Lem (1989), David Hestenes (2011), and others to create awareness in education of the necessity to provide experiences for discrepant events which lead to confront and recognition. Traditional education relies on instructor lecture. Regardless of these experiences being provided or not, such steps are not purely reflective. The reflective parts of the learning cycle are four; they should include identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid. Identifying a phenomenon is also referred to as “naming”\*. Establishing the context for a phenomenon is referred to as “framing”\*. Finding a means of predicting a phenomenon is embraced by traditional scientific methods but to do so reflectively requires an awareness of reason for the prediction. Codifying the circumstances under which the means of prediction is valid usually takes a great deal of experimentation but some reflection on limiting conditions are qualitatively useful. A perfect reflective tool would ideally contain all six components of reflective learning (confronting a novel situation, recognizing the situation as novel, identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid). But any tool designated as reflective must incorporate at least one of the four reflective parts of the learning cycle (identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid). My focus is on reflective tools for use in a unit. I leave perfect reflective tools to curriculum designers who can embrace more class time.

 Since we live in an entirely technological world today, it must be expected that any adult will need to continue learning about advances in technology, changing relations between nations, and his/her changing body and family relations as well. Since reflection is an important aspect of a student’s ability to be successful in any situation which requires learning, it becomes evident that reflection is an important aspect to all people’s ability to be successful in life, not just those about to enter college.

**General tools**

 An obstacle to becoming a reflective individual resides in the belief that there is one correct route (Gearhart, 2009). Explicitly directing a student to be reflective, thus creates an additional task, in the student mind, to add to other requirements. Such is unnecessarily overwhelming. Using the tools which follow will create a reflective student without challenging the student to *know the right way to do it* or making the student *do something extra*.

 Similarly, an educator is overwhelmed with entreaties to practice a certain methodology or use best-practices. In spite of this, professional development is generally desired. “Teachers, who often resent becoming targets of blame for the perceived failures of public education, tend nevertheless to advocate their own versions of the need for professional development and renewal.” (Schön, 1987, p. 15). The tools I describe below may be used as an educator sees fit. They can be used once or repeatedly. One or many can be incorporated into a curriculum or unit. Quite in contrast to *something extra,* the tools provided are in common use and many are themselves considered best-practices. This document serves to qualify the reason for the tools’ success in reflective instruction.

 In these sections, I describe tools which will assist the teacher to encourage students to reflect\*. The first section contains those tools for an instructor to apply. The second section contains those tools for either an instructor or a student to apply. The third section contains those tools for a student to apply to him/herself. A list of all tools is included in Appendix B, List of Reflective Tools.

**Instructor tools:**

 Assign learning commentaries. A learning commentary is a journal of mental activity related to a single concept learned. Reflection on the learning process solidifies the content knowledge, increases motivation by reminding the student of learning taken place, and improves ability to reflect both as a reflection-on-action\* after the fact and as reflection-in-action, as the steps taken are made explicit. Reflection which refers to a completed activity in reference to a frame\* or result is referred to as *reflection-on-action* by Schön (1987). Metacognitive\* development is assured when reflection on the action of learning is recorded. Thus, a learning commentary will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Assign observation logs on demonstrations or videos of a phenomenon. Reflective observation logs, like reading logs will develop reflective skill. The student must think about what will be written while he/she is doing the learning. Observations of important data, thoughts on related phenomena, memories of similar occurrences, questions about the materials or set-up, etc. are recorded. In addition to developing communication skill, a log is a journal of student reflection. Observation logs should be assigned early in the year because the skills developed are used to prevent defensive arguing amongst students and other ways learning can go wrong later (Schön, 1987, p. 168). It may be compared to summative assessment results and thus used to identify weaknesses in student thinking (e.g. valuations of importance, or scope of applicability). Thus, an observation log will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon and, ideally, beginning to find a means of predicting the phenomenon.

 Assign reading logs of chapter readings. Reflective reading logs will develop reflective skill (Gearhart, 2009). The student must think about what will be written while he/she is doing the reading. Thoughts, memories, valuations, learned concepts, notes on difficulties, etc. are recorded. In addition to developing communication skill and improving literacy, a log is a journal of student reflection. As observation logs (described on p. 9), reading logs should be assigned early in the year because the skills developed are used to prevent defensive arguing amongst students and other ways learning can go wrong later (Schön, 1987, p. 168). Also as observation logs (described on p. 9), it may later be compared to summative assessment results and thus used to identify weaknesses in student thinking. Thus, a reading log of an appropriate reading could encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Develop interactive lectures. Interactive lectures requiring peer discussion of concepts has been popularized by Mazur (Mason & Singh, 2010). Giving an answer and defending it to other students reinforces the need for and proper use of vocabulary while simultaneously developing reflection. This improves scientific literacy. Each student’s defense is a fallback to learned concepts and constructed understandings\*. This allows the instructor a formative assessment of student understanding of presented concepts and prior knowledge. Properly developed, an interactive lecture will elicit from a student and require him/her to describe his/her “own largely tacit knowing-in-action” which prevents the learning cycle from going wrong (Schön, 1987, p. 138). The listening students develop a critical thinking skill by deciding if such a defense aligns with their own understandings. Thus, an interactive lecture, if properly designed and employed, will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Direct small group collaboration. The instructor can direct small groups to collaborate on context-rich\* problems (Mason & Singh, 2010). Groups of three or four students, whether heterogeneously or homogeneously constructed are given a task to explore and explain a problem. Problems are best ill-defined\*, complex\*, and incoherent\* because the students will impose a coherence of their own, either an experimental design or a familiar conceptual model (Schön, 1987, p. 42). Content and problem-solving strategies are learned while reflection takes place. Collaboration is assisted by use of white boards (Megowan, 2007). The students are motivated by the real-world components. Dialogue attempts to elicit any useful prior knowledge. A method toward a solution can be attempted and abandoned with group understanding of why the method would fail. Instructor care is placed on asking why students are changing an approach and reminding them that they will need to explain what they are doing to the larger group. Students coach each other to be better students by “observing student performance, detecting errors of application, pointing out correct responses” (Schön, 1987, p. 39), and explaining reasoning. Both experimental and logical methods must be coordinated before a sensible mathematical approach can determine a solution. Thus, small group collaboration will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Direct students to explain consequences of a hypothesis or conversely, what would have to happen to prove a given hypothesis is false. This reflective activity sets the hypothesis as a tentative understanding rather than a fixed datum. The student’s willingness to hold his/her beliefs loosely allows the student the freedom to perceive, compare, and coordinate alternative ideas (Schön, 1987). Thus, the student is allowed the freedom to explore his/her “understanding from an objective standpoint, open to the possibility of change. Part of the reflective process is the ability of a person to see the possibility that [his/her] understanding is capable of error. After all, if our knowledge is perfect, then the need for learning becomes obsolete.” (Gearhart, 2010). The potential for error is a formidable barrier to teenagers who lack confidence. An instructor may “elicit self-discovery in others, first by modeling for others, as a learner, the open expression of his own deepest reflections (however absurd they may seem) and then, when others criticize him, by refusing to become defensive.” (Schön, 1987, p. 92). An instructor may therefore scaffold\* appropriate behavior for student suppositions by implicit modeling. Carl Rogers in that same 1952 reflection referred to earlier, at Harvard University stated an important and difficult point to achieve, as a means of learning, “is to state my own uncertainties, to try to clarify my puzzlement, and thus get closer to the meaning that my experience actually seems to have.” (Schön, 1987, p. 90). I agree completely with that statement, as I have learned most quickly those difficult concepts for which I have personally applied this point. I first noticed the power of the statement in grade school, when I recognized that understanding allowed me to construct solutions more quickly than my peers who were attempting only to memorize the concepts without understanding. Thus, a hypothetical consequence will encourage reflection by either identifying the phenomenon, establishing a context for the phenomenon and finding a means of predicting the phenomenon, or, given the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Explicitly instruct on a pattern of developing a solution. Examples of a pattern are the scientific method or problem mapping. A problem map shows what is known and unknown and steps needed to connect them *without* any computations being done. I have used problem mapping successfully in tutoring Chemistry and Physics for a number of years. By keeping the whole solution pattern abstract, a student asserts it as a mental construct separate from concrete elements (e.g. lengths, masses, accelerations, etc). As a part of the instruction, the instructor must allow the student to use the pattern to solve a problem. At first, have the student use the pattern to solve a familiar problem, so the fundamentals and applicability are grasped. It may be necessary to scaffold this step with an instructor demonstration of its use. Student imitation of the demonstration, then, allows the pattern to be used to solve the familiar problem. “Imitative reconstruction of an observed action is a kind of problem solving” (Schön, 1987, p. 109) which, practiced, develops the understanding that one can learn from imitating. This is an especially important understanding when a population has little self-esteem. The lack of self-esteem forces issues of independence and creates resistance to imitation (a feeling that one is not acting self-determinedly ensues). Then, have the student use the pattern to solve an unfamiliar problem which “is not initially clear and there is no obvious fit between characteristics of the situation and the available body of theories and techniques.” (Schön, 1987, p. 34). The student inquiry will, with practice, follow conventional “rules for data gathering, inference, and hypothesis testing, which allow him to make clear connections between presenting situations and the body of professional knowledge.” (Schön, 1987, p. 34). Schön is referring to content knowledge with his phrase *body of professional knowledge.* Further practice, as described on p. 20 below, will refine reflection on the instruction. Thus, explicit instruction on a pattern will encourage reflection by identifying the phenomenon and finding a means of predicting the phenomenon.

 Explicitly teach a problem-solving strategy. “The abstract nature of the laws of physics and the chain of reasoning required to draw meaningful inferences make it even more important to teach students effective problem solving strategies explicitly.” (Mason & Singh, 2010). An example of a problem-solving strategy is the use of a table to organize voltage, current and resistance of circuit components. See Appendix C – Ohm’s Table for an example problem and table. Application of circuit rules (e.g. Ohm’s Law, current in series is the same at all points or conservation of charge) allows completion of an incomplete table. Such tools are useful to develop concrete operations\* for students to begin handling a topic. But the tool is an abstract, separate from its concrete elements. As a caveat, an instructor must be well familiar with a strategy to be explicitly taught. We tend to inadequately explain how we perform complex tasks (Schön, 1987, p. 25). Furthermore, “some things likely to cause [a student] the greatest difficulty [learning a problem-solving strategy] are just the ones [an instructor] takes for granted.” (Schön, 1987, p. 103). As in explicitly teaching a pattern of problem-solving, the student must be given an opportunity to use the strategy in a familiar situation before an unfamiliar one. Also, a demonstration of use before student application can be used as a scaffold (as in explicitly instructing on a pattern of developing a solution). And practice, as described on p. 20 below, will improve results from explicit strategies. Thus, explicit strategies will encourage reflection by identifying the phenomenon and finding a means of predicting the phenomenon.

 Hold a board meeting. In Modeling Instruction\* (Megowan, 2007), after a paradigm lab\*, small groups create white boards explaining the activity. A class discussion using the white boards follows this (the board meeting). The extent to which paradigm labs promote reflection is dependent on the way the board meeting is handled. Megowan thinks, “A board meeting following a lab is an obvious instance of ‘guided reflection.’ And the subsequent lab write-up causes students to further consolidate the relationships identified and explored in the board meeting and provides the teacher with a snapshot of each student's conceptual model following the lab.” (2011). After the initial concrete experience of the activity, the board meeting provides “the opportunity to articulate the idea in [the students’] own words.” (Arons, 1997, p. 3), which further registers the concepts with the student. “Reflection on others’ understandings of the substantive materials” leads to criticism of perceived errors or ambiguities, which serves as a feedback mechanism to improve learning, dialogue, and relations. This feedback mechanism is essential to avoid learning going wrong (Schön, 1987, p. 138-139). The instructor emphasis during a board meeting should be on appropriate dialogue (e.g. agreed-upon definitions for vocabulary, respectful questioning) and criticism to the end of student agreement on: the frame for the problem in the context of a known model; identity of knowns, unknowns, and assumptions; a map from knowns to unknowns; a range of reasonable solutions both qualitatively and quantitatively; solution to the problem if possible or data needed to solve the problem (Schön, 1987 p. 163-167). Thus, a board meeting will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Use open-ended questions. “We must encourage our students to ask questions when they find class concepts difficult. This will lead our students around small roadblocks so they can see the entire picture we are presenting. We can do this with open-ended questions, reflective listening, and summary statements that build the learning around each new concept or idea. The student will then build some confidence. This leads to self esteem and fosters better learning.” (Pidgeon, 2011). Open-ended questioning provides student opportunity for developing naming and framing skills in addition to content and reflection development. Reflective listening to answers provided to open-ended questions, will model reflection for the student. Asking another student if he/she agrees or disagrees with a particular student and why, will develop critical listening and thinking skills. Fundamentally, the instructor must provide an opportunity for the student to interpret an experience, in his/her own words, or to “tell the whole story [of a problem solving strategy] in [his/her] own words.” (Arons, 1997, p. 4-5). Thus, open-ended questions will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon or codifying the circumstances under which the means of prediction is valid, depending on the question asked.

**Instructor or student tools:**

 Compare and contrast analogies. Use analogy to identify similarities and differences between a novel situation and a familiar one. (Mason & Singh, 2010). Identifying similarities in an analogy will lead a student to transfer problem-solving strategies to novel situations. Arons (1997, p. 35) encourages students to “translate verbal descriptions into graphs,” for example. Identifying differences in an analogy will lead a student to question the applicability of a problem-solving strategy or the validity of an initial assumption. Reflection is developed by familiarization of abstract representations. The analogy need not be limited to a concrete form. Schön (1987, p. 67) describes the familiar situation of an inclined plane conceptual model used as a precedent, or a metaphor to the unfamiliar situation of a pendulum. An advantage of using sufficient exemplars in a curriculum is that the instructor may scaffold discourse with metaphors such as, “we saw this in the … model.” An instructor may also ask a stuck student, “how would you solve the problem if it was a ….” Arons notes “the importance of looking at an abstraction in more than one way” (1997, p. 35) and “full understanding resides not only in knowing what something means, but in also knowing what it does *not* mean” (p. 29). As a student-originated analogy is developed, it must be compared *and* contrasted. Thus, an analogy will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and/or codifying the circumstances under which the means of prediction is valid, depending on the validity of the analogy.

 Consider limiting cases. Use limiting cases to verify that an assumption is valid (Mason & Singh, 2010). This technique forces the student to apply prior knowledge to a concept, predict what is rational and compare that prediction to a determined result. Particularly useful is a student description of why he/she believes what he/she does. This tool can be applied along with analogies (e.g. a falling feather, like a rolling marble, can be so small that it stops falling), or whenever a tacit understanding is applied (e.g. increasing voltage will always increase charge in a parallel plate capacitor). Thus, a limiting case will encourage reflection by codifying the circumstances under which the means of prediction is valid for an identified phenomenon.

 Convert one representation into another. For example, convert a problem from an initial verbal representation to other suitable representations such as a diagrammatic, tabular, graphical, or algebraic representation (Mason & Singh, 2010). As promoted by Modeling Instruction (Megowan, 2007) and (Hestenes, 2011), Arons (1997) and used by Knight texts (2004), this technique requires a student to construct an understanding independent of the representation such that a translation can take place. An independent understanding is closer to abstract knowing than any one representation. This tool is excellent for learning content and improves reflection by getting the student to confront the meaning in each representation. Arons notes “the importance of looking at an abstraction in more than one way” (1997, p. 35). While this tool may be practiced, as described on p. 20 below, by students without instructor presence (which *is* recommended), learning to use *converting between representations* without instructor feedback *is not* likely to result in understanding because students are more apt to abandon an attempt which becomes confusing, excusing it as impossible, than they are to persist through the confusion to a new understanding. Thus, a translation will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Correct work. Correction of homework, quizzes, or tests which require detailed explanations of errors and reasons for the correct actions can be allowed for partial credit. The credit is usually motivational and the explicit communication from the student enforces reflection on learning as well as reinforces ability to communicate. In addition to the reflective nature of the activity, correcting work registers the correct actions or logic needed to solve a problem. Thus, a correction will encourage reflection by accurately identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Develop an operational definition\*. Possibly, from working backward from a desired solution, one may identify the factors needed to construct a solution. In a context of needing to know what is meant and what it is for, one may have operational attention\* while observing a demonstration, performing an experiment, or reading about a problem-solving method. One can then put together action sequences or abstracts of the sequences to form operational definitions. With this attitude of operational attention, one is more apt to be engaged in the learning process, to question the instructor and peers, and to reflect on the significance of observations (Schön, 1987, p. 103). Operational definitions connect concrete experiences to concepts explicitly. Activities may be used to introduce a concept. Use of the compare and contrast analogies, and consider limiting cases tools will further hone an operational definition and lead from concrete to formal operation\* of the definition. Construction of operational definitions by activity and student verbal description of operational definitions by story-telling are encouraged by Arons (1997, p. 3-5). Thus, developing operational definitions will encourage reflection by identifying the phenomenon and, possibly, establishing a context for the phenomenon.

 Interact with peers. Reflection with peers can be accomplished by comparison of white board solutions or projected written solutions from homework, quizzes or tests. Teachers can encourage communication between students to describe the reasoning for each solution step, assumption or representation. This technique is less useful in uninstructed situations because one student tends to direct another in which case no reflection takes place (Megowan, 2007). However, Singh found evidence of co-construction of knowledge without instructor intervention (Mason, Singh, 2010). Interaction can take place in chat rooms or, preferably, in person with paper, chalk board or white board. “Reflection is best made concrete, either on paper, on a whiteboard or in a discussion so that the student’s frame can be evaluated as needed.” (Gearhart, 2010). The students achieve a convergence of meaning both in actions and in vocabulary through the peer interaction. Conclusion of a proper peer interaction will frame or reframe the problem in the context of a known model; identify knowns, unknowns, and assumptions; show a map from knowns to unknowns; show a reasonable solution both qualitatively and quantitatively; solve the problem if possible; and communicate the answer in the original frame with qualifications appropriate to the assumptions made (Schön, 1987 p. 163-167). For the same reasons as small group collaboration (described on pages 10-11) and board meetings (described on pages 14-15), reflection is developed. Thus an interaction with peers will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and, possibly, codifying the circumstances under which the means of prediction is valid.

**Student tools:**

 Practice. While solving problems, even those of mathematical nature, use a full proof format. Write out what is done and include an explanation or reason why that action or assumption is valid. This is not a mechanical action, then, but a reflective activity far more engaging than a standard drill. Content is learned faster and reflection develops as the application of reason is conscious. It should take little time to learn the performance and reason for each step, as these were learned earlier. It may take a little longer to remember the sequence of all the steps. But, while an understanding of the reason for the sequence is had before-hand, true knowledge of the meaning for the sequence will not develop until after duplication of the sequence as a whole is complete. For an action which is a sequence of steps, meaning about the purpose for the action develops after action is repeated in this tool. Schön suggests an instructor “tries to get the student to perform a particular operation in order to become aware of its function in the situation” (1987, p. 106). In application, multiple operations are necessary to accomplish the desired result. Duplication is essential. Thus practice will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Take notes. While listening to lectures, watching demonstrations, or reading; a student should take notes. The observation, thoughts about it, predictions, unknown words, sample solutions and questions should be recorded. I usually put unknown words and questions in a separate color to make them easier to find later. Afterward, additional thoughts, definitions, answers to questions and analysis of predictions should be noted. Reflective comments about difficulty of concepts, beliefs about values of observations and concepts, predictions about what will be on the exam and why such is considered valuable should always be included. In my own notes, I go through each day’s notes after class and note page numbers (from notebook, textbook, and lab book) and useful websites which contain related information. This explicitly reminds me of the connection to prior knowledge and extensions, and makes study for final examination easier. After examination, comparison of notes to what was missed will reveal patterns of incomplete notes. For example a day or a solution example was missed, or an observation was misinterpreted. Thus, taking notes will at least get the student to engage in some part of reflection. As student note-taking improves, taking notes will ideally encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and codifying the circumstances under which the means of prediction is valid.

 Use self-explanation. Self-explanation is a process of explicitly explaining to oneself what one is learning (Mason & Singh, 2010). Identification of new concepts, how they work, what prior knowledge is so related, and context in which the concept applies actively constructs knowledge. For example, provided with a scenario, one can predict the outcome and explicitly state why that is expected. The actual result is then compared to the prediction and any discrepancy is worked out, a reflection-on-action. Self-explanation can be spoken aloud or written down. Some degree of discipline is required on the part of the student to not skip steps if self-explanation is done silently to oneself. Humans tend to ignore what they don’t understand so prior practice with developing questions is useful. Thus, a self-explanation will encourage reflection by identifying the phenomenon, establishing a context for the phenomenon, finding a means of predicting the phenomenon and, possibly, codifying the circumstances under which the means of prediction is valid.

**Mechanics application**

 In this section, I present one instructor tool for use in a specific mechanics topic to reinforce a reflective learning environment. The instructor tool I present is small group collaboration. The specific mechanics topic, in which small group collaboration takes place, is graphing position versus clock reading, presented in a rectilinear kinematics unit. I include what prior knowledge I expect students to have, expected difficulties related to reflection, instructional strategies to overcome these difficulties, and also the relation of graphing position versus clock reading to NYS Core Curriculum.

 Small group collaboration is described on pages 10-11. In the context of graphing position versus clock reading, students are given the task to create graphs of position with respect to time and to explain the results as a group, to the class as a whole. Range finders and a clock are made available, or, alternatively, either tape measures and watches are made available, or a computerized range finder and some data collection and analysis program (e.g. Logger Pro©) is provided to each group. If a computerized range finder and some data collection and analysis program is provided to each group and white boards (2’ X 3’ size) are available, a kinesthetic approach is seen. One student holds the white board toward the range finder to provide a good signal and walks toward and away from it while another student is collecting data. The observed motion coupled with the graphical display “register the concepts” (Arons, 1997, p. 29). Instructor emphasis is on directing the students to show the motion and graph on the white board, and making sure that *each* student in a group can explain how the motion corresponds to the graph. Although such an activity as described herein is followed by group presentation of results to the class as a whole, I limit my comments to the activity of small group collaboration part of the activity, for simplicity.

 Prior to beginning a unit on rectilinear kinematics, a student is expected to have some knowledge of mathematics and science. Particular to mathematics, a student should have some understanding of change (difference) and graphing. Particular to science, a student should have some understanding and at least some experience with the range finder, the data collection and analysis program, group work, white board presentation, relative position, and clock reading. In addition, it would be helpful if students have been exposed to the difference between a position (point in space) and a length (difference between points), and similarly to the difference between an instant (point of time) and an interval or duration (difference between instants), these being the physical applications of mathematical differences. The concept of change is pertinent to finding lengths and durations. The process of graphing is a fundamental skill which, if absent, will result in serious misinterpretations of the graph and communication between students. Familiarity with equipment and programs is useful for rapidly moving from task orientation to data acquisition to analysis. The faster the students can progress, the more likely they are to stay interested and focused. Familiarity with group work and white board presentations falls under mode of learning. Transitions consume time when they are not drilled beforehand. The concept of relative position is important to avoid confusion of where in the room the origin of the graph represents as well as clarifying dimensions; the activity as described has one dimension (position measured from the range finder) regardless of the direction it is pointed. The concept of clock reading is important to differentiate time as an instance and time as an interval as well as to avoid confusion of when in reality the origin of the graph represents (Arons, 1997, p. 25).

 While graphing position versus clock reading, it is expected that students will have trouble with technology, giving verbal interpretations of lengths in their position versus clock reading graph (vertical, horizontal or diagonal) (Arons, 1997, p. 29). Trouble with technology can occur when settings are changed or defaults are restored. These are more frequent if the students are not familiar with the technology and/or the students are particularly curious (not a bad thing). Instructor familiarity with the equipment is essential in preventing such setbacks and correcting them quickly when they crop up. Student difficulties in verbal interpretation of lengths in their position versus clock reading graphs result from lack of prior knowledge, misunderstanding of prior knowledge, inattentiveness during data collection, or an inability of the student to bridge the gap from the concrete event to the abstract representation of the event. Lack of prior knowledge can be determined by careful questioning, working back until a certainty of concept is ascertained and the working forward again until the student grasps current events. Misunderstanding of prior knowledge is also determined by careful questioning but while the instructor is working back to a certainty of concept, the student will originate a false datum. Continued questioning of how the student believes this while pointing out known contradictions will eventually overcome the false belief preventing learning. Inattentiveness during data collection can be determined by questioning what the student did (maybe nothing as the other group members worked). If questioning does not produce recall of events (student may have been texting or daydreaming), the activity will have to be replicated. An inability to bridge the gap between a concrete event and the abstract representation of the event may be overcome by encouraging students to work forward from the motions observed to the graph they drew and backward from the graph to the motion. If this continues difficult, an exercise of using the hand to describe motions given by a particular graph will scaffold the students into developing the appropriate concepts (Arons, 1997, p. 28). Thus, any difficulty the student encounters may be remedied.

 Graphing position versus clock reading meets the requirements of the NYS Core Curriculum. Specifically, graphing position versus clock reading provides for STANDARD 1 – Analysis, Inquiry, and Design by representing physical quantities in graphical form, constructing graphs of real-world data, and explaining the physical relevance of properties of a graphical representation of real world data. Further, this topic provides for STANDARD 2 – Information Systems by using appropriate technology to gather experimental data, develop models, and

present results. Further, this topic provides for STANDARD 7 – Interdisciplinary Problem Solving by collecting, analyzing, interpreting, and presenting data, using appropriate tools. (Physical Setting Physics Core Curriculum, 2011). While this topic is covered early in the course and provides for few standards, it contains concepts which are fundamental and which are built upon later (Arons, 1997, p. 1), in providing for more standards. Furthermore, it is advisable to continue construction of concepts by spiraling back to more fundamental concepts in later units (Arons, 1997, p. 1). Thus, while instructing required material, an instructor may be providing for his/her students’ continued reflective development.

 I have presented small group collaboration as an instructor tool for use in graphing position versus clock reading, a typical topic of a mechanics unit, as an example of a reflective strategy. The expected prior knowledge of students has been presented, along with expected difficulties. Some instructional strategies to overcome the listed difficulties have been presented. Reference to the NYS Core Curriculum has been presented. While many possible instructor and/or student tools exist to promote reflection within this unit and any combination may be used, the use of small group collaboration as a strategy has been described and explained.

**Assessment**

 Students can demonstrate an improved level of reflection after instruction. The demonstration is in the form of changes in affective\* comments. The changes reflect improvement by showing an increased degree of reflection. Both formative\* and summative\* assessment is possible.

 Formative assessment is possible with open-ended questions as “I don’t know” type answers will give way to progressively more detailed responses connecting prior knowledge to a problem-solving strategy (Schön, 1987, p. 65). It is also possible with reading logs, observation logs, notebook checks, ticket-out-the-door comments, test or quiz corrections, or informal verbal comments (to instructor or overheard between students). Comments on the order of, “I’m not learning anything.”, or even, “You aren’t teaching me.”, convey little metacognitive acumen. However, these comments adequately demonstrate the low reflective development of the student. “Why are we learning this?”, “Are we supposed to believe gravity is a force?”, and other such questions convey reflective development. Metacognitive comments (e.g. “drawing force diagrams make me tired”) show a greater degree of reflection. On a gradient scale of ability, students will improve until, one hopes, he/she achieves comments along the line, “I should have applied a constant acceleration model because the problem specified a uniform field.” Such comments identify the concept missed so one can assume that learning took place; not only will this mistake not be made again but the possibility for that type of error will be watched for.

 Summative assessment is possible with observation of group collaboration or board meetings. Explorative communications will give way progressively to more commitment. For example, a student early in an acceleration unit may question if a changing velocity implies a novel situation since average velocity will take changes into account. Later, this student may defend his position that the constant acceleration model is not necessarily valid for an ill-defined system. It is likely that a high school student will not achieve a mastery of metacognition in one course. But it is possible to chart change of a student’s reflective level through a unit or a course.

 Keeping track of metacognitive ability for each student is probably desirable for an instructor who cares about metacognition. Some note could be made for each student during each unit and a map of progress (or lack thereof) would reveal itself. The basic series would move from a not-know condition to a know condition. The possibilities of comments which reveal the condition are endless. The series was characterized by L. Ron Hubbard (1951); see appendix A, Know Scale. So long as a student is exhibiting increasing degrees of knowing in his/her communication and notes recording this are written, improvement in reflection is proven. Care need be taken in applying the scale as any confidently stated misconception is as likely an attempt to prove one cannot understand as it is an indication that one is trying to understand. But these subtleties are better worked out in-action.

**Conclusion**

 Metacognition plays a role in deciding what factors are to be included in any problem to be solved. The problem of learning is a self-imposed one which must be overcome to allow success in our technological society. Reflection on learning will help a student become an independent learner by developing metacognition. Reflection is therefore a powerful tool in equipping students to be independent learners, useful in education not just for metacognitive development but developing ability gather useful information and apply knowledge to problem-solving. Reflection is the bridge between knowledge a student has and the uncertainty students will face.

 Reflective skill is developed mainly by discussing what one does and listening to what others do in a problem-solving context. A dialogue is necessary for feedback and feedback is necessary for rapid development. Schön encourages a reflective practicum whose “main features are learning by doing, coaching rather than teaching, and a dialogue of reciprocal reflection-in-action between coach and student (1987, p. 303). While a coordinated curriculum taught through such a practicum is an ideal held up by many other educational professionals (among them Arons, Hestenes, Lem, Megowan, and Vygotsky), reflective elements may be incorporated without complete overhaul of curriculum or methodology.

 I have provided a list of tools which are in common use and many of which are themselves considered best-practices. The tools are organized in three sections: those tools for an instructor to apply, those tools for either an instructor or student to apply, and those tools for a student to apply to him/herself. I have shown an example of using a tool (small group collaboration) within the context of a specific mechanics unit (graphing position versus clock reading).

 I have described the assessment of students pertinent to their reflective ability based on instructor observations of writing and dialogue of the student. The plotting of observed statements against a gradient scale of knowing, over time shows reflective development.

 Reflection is a vital component of problem solving in a complex, ill-defined, incoherent context. Such problems abound in the real world. The use of reflective tools in a secondary education science classroom is likely to produce students much more capable of applying their knowledge and skills to their post-secondary life.

**Appendices**

**Appendix A – Know Scale:**

 I know

 I understand

 I am trying to understand

 I will not understand

 I am afraid to understand

 I cannot understand

 I know not

**Appendix B – List of Reflective Tools:**

Instructor tools:

 Assign learning commentaries.

 Assign observation logs on demonstrations or videos of phenomenon.

 Assign reading logs of chapter readings.

 Develop interactive lectures.

 Direct small group collaboration.

 Direct students to explain consequences of a hypothesis.

 Explicitly instruct on a pattern of developing a solution.

 Explicitly teach a problem-solving strategy.

 Hold a board meeting.

 Use open-ended questions.

Instructor or student tools:

 Compare and contrast analogies.

 Consider limiting cases.

 Convert one representation into another.

 Correct work.

 Develop an operational definition.

 Interact with peers.

Student tools:

 Practice.

 Take notes.

 Use self-explanation.

**Appendix C – Ohm Table:**

The problem:

 Given the light bulbs shown in the circuit are the same, what can you determine about electricity in the various legs of the circuit?



The table:

 Filled in from knowns, with no rules or inferences applied.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Change in voltage(volts) | Current(amps) | Resistance(ohms) |
| A to B |  |  |  |
| B to C |  | 0.5 |  |
| C to D |  |  |  |
| D to A | 1.5 |  |  |

**Appendix D – Glossary:**

Each term is asterisked the first time it appears. Definitions (and example sentences where necessary) are included with the first context and page on which it appears.

complex – requiring multiple steps each of which is not necessarily difficult <A problem with mixed units is *complex*.> <Problems are best ill-defined, *complex*, and incoherent. p. 11>

concrete operation – reference to Piagetian learning stage characterized by physical actions and/or mechanical understandings in contrast to formal operations (which uses abstract concepts) <Tools are useful to develop *concrete operations* for students to begin handling a topic. p. 14>

context-rich – including multiple real-world components in contrast to an unrealistically simplified version <The instructor can direct small groups to collaborate on *context-rich* problems. p. 11>

formal operation – reference to Piagetian learning stage characterized by mental abstraction in contrast to concrete operations (which uses physical actions) <Use of the compare and contrast analogies, and consider limiting cases tools will further hone an operational definition and lead from concrete to *formal operation* of the definition. p. 18>

frame – context for a given situation which influences the way the situation is perceived and treated < Reflection which refers to a completed activity in reference to a *frame* or result is referred to as reflection-on-action by Schön (1987). p. 9>

framing – creating a frame, specifically consciously creating a frame within which the given situation may be resolved < Establishing the context for a phenomenon is referred to as *framing.* (Schön 1987, p. 4). p. 6>

ill-defined – purposely provided without vocabulary; no naming clues given to a phenomenon <An *ill-defined* gravity problem will often fool students into using a wrong model.> <Problems are best *ill-defined*, complex, and incoherent. p. 11>

incoherent – purposely provided without a frame; no framing clues given to situation <An *incoherent* problem is open to student interpretation and requires stated assumptions in the solution.> <Problems are best ill-defined, complex, and *incoherent*. p. 11>

know – ability to comprehend a concept in any context in contrast to understand <I *know* how to speak English.> <This is just what we don’t *know* how to teach. p. 5>

metacognition – ability and willingness to think about one’s own thoughts and thought processes <Reflection on learning, specifically, will enhance a student’s *metacognition*. p. 4>

metacognitive – having to do with awareness of one’s own thinking; contributing to metacognition <*Metacognitive* development is assured when reflection on the action of learning is recorded. p. 9>

Modeling Instruction – A teaching method developed from a social constructivist perspective (Hestenes, 2011) <There are multiple labs in a sequence, within a unit of *Modeling Instruction*.> <In *Modeling Instruction*, small groups create white boards explaining the activity. p. 14>

naming – creating a name, a group specifically consciously agreeing on a name for an observed phenomenon < Identifying a phenomenon is referred to as *naming.* p. 6>

operational attention – conscious awareness of what is being done due to the necessity to replicate it oneself <In a context of needing to know what is meant and what it is for, one may have *operational attention*, p. 18>

operational definition – a meaning composed of a series of activities which construct a concept in contrast to a meaning which only describes or one which purports a purpose <An operational definition of down is given by the direction of a string held fixed at one end and attached to a free plumb bob on the other when the plumb is not swinging.> <Develop an *operational definition*. p. 18> (Arons, 1997, p. 2)

paradigm lab – an experimental activity which serves as an archetype example for the basic problem to be solved in a unit; first lab of a sequence of labs in a unit of Modeling Instruction (Merriam-Webster, 1994), (Hestenes, 2011) <The *paradigm lab* serves as a concrete experience on which to construct an abstract model.> <After a *paradigm lab*, small groups create white boards explaining the activity. p. 14>

reflect – to think about, specifically to think about with respect to learning <Students should be encouraged to *reflect* on their errors.> <I describe tools which will assist the teacher to encourage students to *reflect*. p. 8 >

reflection – “a thought, idea, or opinion formed or a remark made as a result of meditation” (Merriam-Webster, 1994); process of reflecting, specifically reflecting with respect to learning < *Reflection* is an amazing human tool. p. 4>

reflection-in-action – process of reflecting on an action sequence which one is performing <*Reflection-in-action*, according to Schön (1987) is “thinking [of] what they are doing while they are doing it.” p. 4>

reflection-on-action – process of reflecting on an action sequence either prior to or after completing performance of the sequence <His *reflection-on-action* after making the jump led him to believe he could jump farther.> <Reflection on the learning process solidifies the content knowledge, increases motivation, and improves ability to reflect as a *reflection-on-action*. p. 9> <Reflection which refers to a completed activity in reference to a frame or result is referred to as *reflection-on-action* by Schön (1987). p. 9>

reflective – having to do with reflecting; contributing to reflection <*Reflective* learning is an extensive process. p. 5>

scaffold – to provide a lower gradient step as a bridge from the student’s zone of proximal development\* to the desired functional level <An instructor may therefore *scaffold* appropriate behavior for student suppositions by implicit modeling. p. 12>

understand – ability to comprehend a concept in a context in contrast to know <I *understand* the constant velocity model in an inertial reference frame.> <Each student’s defense is a fallback to learned concepts and constructed *understandings*. p. 10>

zone of proximal development – the range of student function which is optimal for learning: not too easy but not impossibly difficult <Intrinsic motivation is highest in the *zone of proximal development.*> <Provide a lower gradient step as a bridge from the student’s *zone of proximal development* to the desired functional level. p. 36> (Vygotsky, 1978)

**Annotated References**

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**Biography**

 Charles Abramo was born in Western New York. He attended Hamburg Senior High School where he developed an interest in science and tutoring. After high school graduation, he immediately attended Clarkson University where he earned a bachelor’s degree in Chemistry. He briefly pursued an advanced degree in analytical chemistry at Florida State University before employment with Ecology & Environment in Lancaster as a lab technician operating high performance liquid chromatography equipment. After changing career paths to the teaching profession, he tutored many students through troubled subjects. Through Buffalo State College, he is certified to teach general sciences grades 7-12, and, at high school level, Physics and Chemistry in New York State and has been teaching in Western New York schools since 2004. He is currently attending Buffalo State College for a Master degree in Physics Education.