Reforming Physics Instruction Via RTOP

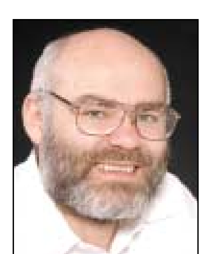
Dan MacIsaac and *Kathleen Falconer*

Professional associations of scientists, mathematicians, and educators have called for extensive reform in the teaching of science and mathematics.[1,2] Their reports critique U.S. science and mathematics curricula as *largely incoherent, excessively repetitive and unfocused* — "a mile wide and an inch deep."[2] In 1995, the National Science Foundation funded a large five-year collaborative project called the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) at Arizona State University.[3,4] Recognizing that most teachers teach as they were taught, ACEPT decided to "break the cycle" by reforming the freshman science and mathematics classes taken by preservice teachers. Freshman science and mathematics courses would be *reformed* — that is, taught via the kinds of constructivist, inquiry-based methods advocated by professional organizations and researchers so that these future teachers would be taught as they were expected to teach. To assess whether *reformed teaching* was occurring in classes, the ACEPT evaluation team developed a classroom observation instrument called the Reformed Teaching Observation Protocol (RTOP), which both measures and operationally defines *reformed teaching*. In its present form, the RTOP is a highly reliable instrument with strong predictive validity.[5,6] To date, RTOP has been used in more than 400 K–20 science and mathematics classrooms to provide a precise quantitative reading of the degree to which teaching is *reformed*. *RTOP both operationally defines and assesses* ***reformed teaching*** *in the classroom — we henceforth explicitly reserve and define the term* ***reformed teaching*** *to mean those classroom practices that result in a high RTOP score.*

In the evaluation of ACEPT, RTOP scores were found to strongly correlate with student conceptual gains (Fig. 1), showing that reformed teaching is also effective teaching. Because the correlation coefficients between RTOP and student achievement gains were so high (correlation coefficients in the 0.70–0.95 range

Dan MacIsaac is an assistant professor of physics at SUNY–Buffalo State College, where he specializes in physics teacher preparation. He earned bachelor's degrees (B.Sc. in physics; B.Ed. in secondary science and mathematics teaching) from Mount Allison University; an M.A. in science education from the University of British Columbia, and M.S. (physics) and Ph.D. (physics education) degrees from Purdue University. MacIsaac is active in AAPT and on the PHYS-L listserv.

Department of Physics
SUNY–Buffalo State College
1300 Elmwood Ave., Buffalo, NY 14222;
danmac@att.net



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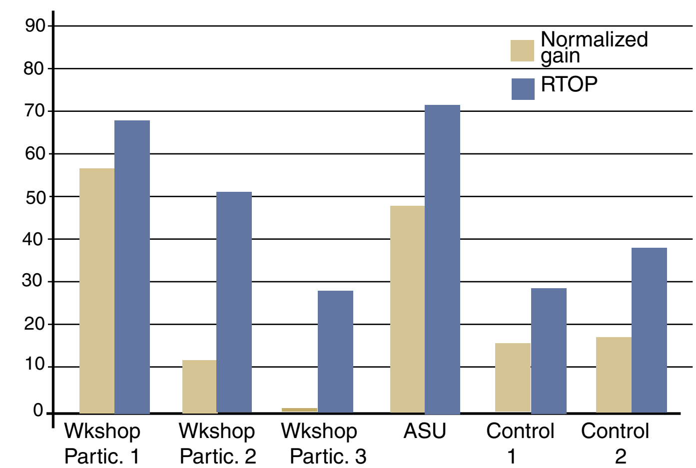

RTOP scores are averaged across three observations by two or more observers (interrater reliability > 0.80).

The PCS contains a subset of the FCI. The correlation coefficient between Normalized Gain and RTOP is 0.88.

These and similar data published in Ref. 6.

Fig. 1. ACEPT PHS 110 Fundamentals of Physical Science. Average RTOP vs Normalized Gain on physics concept survey.

were typical), it occurred to us that the items in the instrument might provide teachers as well as researchers with a window into understanding reformed teaching.

There are two notable sets of research on classroom behavior that are linked to student achievement — the physics education research of Richard Hake and the science education research done on cooperative learning. Hake[7] published a large-scale study of more than 6000 introductory mechanics students, finding that interactive-engagement (heads-on, hands-on) strategies produced increases in student achievement well beyond those produced with traditional instruction. A large body of education research reports that student classroom collaboration increases retention and on-task behavior, promotes achievement, positive attitudes, and self-esteem, and produces higher student achievement.[8] *The RTOP instrument is designed to constructively critique details of classroom practices including cooperative learning, interactive engagement, and certain classes of PER activities, as well as findings collectively known as pedagogical content knowledge (PCK).*[9]

What Do Teachers Get from Using RTOP?

RTOP is valuable because it can be used by both new and veteran teachers to not only score their own teaching, but more importantly to acquire insight into their own teaching practices that guides their instructional improvement and professional teaching development. Teachers using RTOP must work with a respected and trusted peer. RTOP scoring and initial reflection takes about 90 minutes, including one hour spent observing the lesson scored.

RTOP specifies a set of 25 scored, observable classroom behaviors or items. Items catalyze teacher development when each is used as a focus for reflection, discussion, and debate upon observed teaching. Constructively critical discussion and debate upon what these RTOP characteristics mean and how they manifest in actual classroom activity underlie the development of a common language of reformed teaching grounded in personal experiences. We consider the development of a common language describing reformed teaching to be the most fruitful outcome of RTOP use by teachers — teachers are unfamiliar with reformed teaching, and all meaningful learning requires the development and refinement of precise conceptual language.[10] RTOP items address behaviors that lie at the heart of learning science and mathematics in the classroom, unlike broader instructional rubrics such as Madeline Hunter's Elements of Effective Instruction.[11] In some cases, these other classroom rubrics are incompatible with inquiry science learning — e.g., Hunter's rubrics for direct instruction in the classroom are centered upon teacher-directed behaviors such as "anticipatory sets" and "closure."

Kathleen Falconer

Kathleen Falconer is a lecturer in elementary education and reading at Buffalo State College, and is currently finishing her Ph.D. graduate research in elementary science teacher preparation at Arizona State University. She earned bachelor's degrees from Mount Allison University (B.Sc. in physics, mathematics, and chemistry; B.Ed. in secondary science and mathematics teaching), and master's degrees (M.S.Ed. in science education; M.S. in physics) from Purdue University. Falconer chairs the AAPT Committee on Women in Physics.

Department of Elementary Education and Reading
SUNY–Buffalo State College
1300 Elmwood Ave.
Buffalo, NY 14222

Student small group discourse in the lecture theater.

Teachers working with us have found that the RTOP is useful as a checklist for lesson planning purposes, in the mentoring and professional development of new or student teachers, and for their own personal pedagogical growth. Another commonly cited use is in defense of instructional change — for example, justifying the modeling method to administrators and parents who may be familiar with traditional instructional methods and require assistance in judging reformed teaching. Many aspects of inquiry teaching challenge traditional practice, and teachers tell us that RTOP helps validate and refocus their own journey into professional growth.

Getting Your Own RTOP Score

To obtain an RTOP score of one of your own lessons: (1) Download the RTOP Training Manual[5] and print a copy for yourself and a teaching colleague whom you trust and respect, ideally familiar with teaching your subject. (2) You and a colleague should read and discuss the instrument, then (3) arrange for your colleague to visit your class to observe and RTOP an hour lesson. (4) While your colleague observes your class, have a student or aide videotape your lesson. (5) RTOP this videotape yourself, before discussing your colleague's RTOP score of your lesson. (6) Reciprocate — perform an RTOP observation on your colleague in turn. This will provide more needed classroom observation material for discussion and genuine meaning in this experience for both of you. (7) Meet with your colleague to discuss and attempt to reconcile the scores on each of the 25 items. Inevitably, you will disagree with your colleague. Use the differences as a focus for reexamining your own teaching practices.

The RTOP instrument items are divided into five sections: (1) lesson design and implementation information, (2) propositional content knowledge, (3) procedural content knowledge, (4) classroom culture (communicative interactions), and (5) classroom culture (student-teacher relationships). These five sections include 25 observable items scored from 0–4 as follows:

0 the behavior never occurred
1 the behavior occurred at least once
2 occurred more than once; very loosely describes the lesson
3 a frequent behavior or fairly descriptive of the lesson
4 pervasive or extremely descriptive of the lesson

— where the exact details of the intermediate scores differ for each of the 25 items and have been rigorously defined by researchers. For your use, when in doubt, err on the side of a lower score. If you feel uncomfortable with a five-step gradation, try assigning only scores of 0, 2, or 4 (absent, sometimes present, always) for an item. If you didn't directly observe an item, it scores as zero (do not make any inferences without training).

When we conduct RTOP teacher workshops scoring video vignettes, teachers usually score lessons artificially high on their first attempts; after more discussion and more video vignettes, the scores typically fall quite dramatically, indicating that teachers rapidly become more discerning. The scores you and your colleague generate will not be as accurate as that of a trained observer and thus will not be useful for formal research. However, your informal scores and discussion will generate comments, insights, and ideas that you can act upon for your own teaching growth, and this experience will enable you to discuss reformed teaching with colleagues. If you have fast Internet access, we have placed some web-streamed video of physics teaching together with expert RTOP scores.[5]

Summing the 25 item scores results in an RTOP lesson score ranging from 0–100 describes the degree of reformed teaching present. For physics lessons we have observed, some typical scores are:

• traditional university lecture (passive)	< 20
• university lecture with demonstrations (some student participation)	< 30
• traditional high school physics lecture (with student questions)	< 45
• partial high school reform (some group work; most discourse still with teacher)	< 55
• medium sized (100 > n > 50) university lectures with Mazur-like group work (ConcepTests) and a student personal response system	65–75
• the author's modified (whiteboards, etc.) large (170 > n > 75) lectures	70–75
• modeling curriculum (varies with amount and quality of discourse)	65–99

These totals are generalized and approximate, and large departures have been observed. *Any RTOP score greater than 50 indicates considerable presence of "reformed teaching" in a lesson.*

The 25 items in the RTOP can be briefly summarized for physics teaching as follows:

• **Lesson Design and Implementation.** The creation of physics lessons that: (1) respect student preconceptions and knowledge, (2) foster learning communities, (3) explore before formal presentation, (4) seek and recognize alternative approaches, and (5) include student ideas in classroom direction.

• **Content (Propositional Knowledge).** Teachers knowing their physics and teaching lessons that: (6) involve fundamental concepts of physics, (7) promote coherent understanding across topics and situations, (8) demonstrate teacher content knowledge (e.g. apparently "unrelated" questions), (9) encourage appropriate abstraction, and (10) explore and value interdisciplinary contexts and real-world phenomena.

• **Content (Procedural Knowledge).** Physics lessons that use scientific reasoning and teachers' understanding of pedagogy to: (11) use a variety of representations to characterize phenomena; (12) make and test predictions, hypotheses, estimates, or conjectures; (13) include critical assessment and are actively engaging and thought provoking; (14) demonstrate metacognition (critical self-reflection); and (15) show intellectual dialogue, challenge, debate negotiation, interpretation, and discourse.

• **Classroom Culture (Communicative Interactions).** The use of student discourse to modify the locus of lesson control such that: (16) students communicate their own ideas in a variety of methods; (17) teachers' questions foster divergent modes of thinking; (18) lots of student, particularly interstudent, talk is present; (19) student questions and comments shape discourse — the "teachable moment" is pursued; and (20) there is a climate of respect and expectation for student contributions.

• **Classroom Culture (Student-Teacher Relationships).** Lesson interactions where: (21) students actively participate (minds-on, hands-on) and set agendas; (22) students take primary and active responsibility for their own learning; (23) the teacher is patient (plays out student initiatives and is silent when appropriate); (24) the teacher acts as a resource and students supply initiative; and (25) the teacher is a listener.

Sample RTOP item 23 scores are described below from physics classes we have observed:

(23) ***In general, the teacher was patient with students.*** Patience is not the same thing as tolerating unexpected or unwanted student behavior. Rather there is an anticipation that, when given a chance to play itself out, unanticipated behavior can lead to rich learning opportunities. A long "wait time" is a necessary but not sufficient condition for rating highly on this item.

Sample ratings for an introductory lesson on rotational kinematics when a student asks "So how does this relate to the movement of the planets?":

Score	Teacher Action
0	Teacher informs the student: "*Don't go there, that's for a later lesson*" or ignores the student.
1	Teacher gives a short answer to the student's question.
2	Teacher turns the question back to the rest of the class and awaits students' responses. After a few responses, the teacher gives correct response incorporating some of the students' correct ideas.
3	Teacher turns the question back to the rest of the class. Gauging that students are interested, the teacher asks students to get into their groups and discuss the question.
4	Teacher turns the question back to the rest of the class. Gauging that students are interested, the teacher shows the students data for the Earth's orbit around the Sun and asks students to get into their groups to try to figure out "How far does the Earth travel in a year?" and "What is the Earth's angular velocity?"

There is an internal tension between patience and the teacher's pedagogical knowledge. The teacher may be tempted to circumvent the inquiry process by not allowing the student enough time to explore his or her ideas because the teacher knows where most students will have problems. However, having the students in control of their learning does not imply that the teacher abdicates responsibility for the classroom and learning. Rather, the teacher has to set up the appropriate problems, and know how and when to facilitate student inquiries so that students reach a goal of common understanding. An expert physics teacher readily identifies and aggressively pursues the "teachable moment" in a lesson, whether or not it is the scheduled one. Although teacher expertise is required to score well on this item, the critical idea is to permit students the time to explore apparently incorrect ideas, to wrestle with the language, and to negotiate with peers.

Inquiry values the student's right to explore and negotiate in a supportive environment. It is *extraordinarily* difficult for teachers to shut up and allow students this freedom, yet teaching via student dialogue is a critical lesson for teachers to learn.[12]

Lessons Learned from RTOP

The 25 RTOP items lay out a set of nontraditional themes for physics lessons, which in turn suggest particular opportunities for reforming physics teaching. We feel two of these themes are the most worthwhile kinds of professional challenges that physics teachers should undertake.

First, and most important, RTOP requires a radically new kind of teaching with a radically new role for the teacher. This is a complete change from the traditional culture of physics lectures.[4] Reformed teaching looks quite different from traditional physics lessons; the biggest single change is that the class is no longer focused on the teacher. The classroom is quite noisy, and the instructor works as a group facilitator, which is quite a different skill than lecturing. Reformed classroom management is quite different: Considerable time must be found for student talk, usually by sharply reducing course topical breadth and by largely eliminating lecture. *The textbook is de-emphasized (or abandoned), as there is insufficient time to present it in class.* Rather than introducing content via lecture, exploratory activities are organized and carried out. It is *very* hard for teachers to allow students to explore and be wrong or incomplete for what seems to be *excruciatingly protracted* periods of time.

Student talk is far more important than teacher talk — high RTOP scores require cooperative student learning through extended dialogue. Teachers choose activities that foster such dialogue and manage, support, and reward student discourse. These activities are carefully chosen to fit within time constraints, to be essential to the concept, and to be sufficiently challenging so that collaboration is necessary. Students discuss, negotiate, reflect upon, and evaluate one another's words and ideas in small groups. Students take time to negotiate meaning, and teachers respect the students' right to pursue blind alleys. In large classes, the teacher will not be immediately available to help groups, and groups must be prepared with self-help strategies. Groups must exchange and negotiate amongst one another as well as within the group. Lectures are reshaped into classroom learning communities, focused on group learning and student dialogue.

Group participation and products are graded, though grading for correctness often is deferred to exams or homework. Reformed teaching lesson materials and activities management is considerably more difficult than traditional lecture, and some students will be highly resistant to taking on the additional work and responsibility reformed teaching requires of them. Thankfully, there are benefits — greater conceptual learning gains, greater participation and success for traditionally less successful physics students, and intrinsic motivation for learning physics.

Second, there is no "golden road" to physics teaching — RTOP affirms the importance of specialized preparation, knowledge, and professional development for physics teachers. Specialized physics teaching knowledge includes skills and content knowledge not required of physicists or of teachers of subjects other than physics. This is called pedagogical content knowledge (PCK) in general science education literature.[9]

Physics PCK includes those touchstone situations, activities, and problems identified by Physics Educatiion Research as having strong impacts upon physics learning. Physics PCK includes student preconceptions research (such as students' confuting position and velocity based on automobile riding experiences), topical emphasis issues (e.g., which kinematics concepts are critical to supporting Newton's laws), and appropriate use of physics examples and analogies (e.g., assimilating electrostatics by developing simpler ideas underlying gravitation into generalized fields). Physics PCK is developed through specialized training and experience in physics teaching and is extended through professional development such as physics curricular workshops, professional physics teaching journals, associations and meetings, and books about physics teaching.[13]

More general science education PCK includes knowledge of inquiry teaching and assessment, the nature of science, and how to foster and support classroom dialogue so as to take advantage of those "teachable moments" you identify using physics PCK. Physics teachers require a thorough knowledge of course content so as to be able to shift the lesson content in line with student thinking, often resulting in very nontraditional sequences. Such shifts require expertise in identifying and underscoring real-world examples as they spontaneously arise.

There are many teaching techniques and curricula that foster the kinds of lessons that score well on the RTOP rubric, and not all lessons can score high on RTOP. One technique that we strongly encourage adopting as part of RTOP self-evaluation is whiteboard use. Whiteboards were developed for use in Hestenes' Modeling Physics curriculum, and whiteboards[14] facilitate cooperative group learning by anchoring student dialogue in a shared, negotiated, and explicit external representation. It is also possible to foster dialogue through the use of cooperative techniques such as think-pair-share, Mazur's ConcepTests with group reporting via personal response systems, or by cooperative group completion of touchstone PER-identified problems.

Like all worthwhile endeavors, reformed teaching is a challenging, often difficult, and richly rewarding adventure. We encourage you to try this approach for your professional growth as a teacher and for the conceptual growth of your students. You'll also learn lots of physics from listening to and reflecting on the ideas of your students.

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