A Curriculum for Teaching the Foundation Tool Skills to First-Year Orthopaedic Surgery Residents

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Abstract

Background: In an effort to satisfy the American Board of Orthopaedic Surgery (ABOS) requirement for a month-long orthopaedic skills rotation, programs often construct a skills curriculum that is procedurally based. As an alternative, we describe a skills program that teaches individual tool skills to fluency (accuracy at speed) using instructional modules that are innovative, challenging, inexpensive, and when combined with an operant learning program, encourage deliberate practice.

Methods: The orthopaedic faculty identified 14 surgical tools that postgraduate year one (PGY-1) orthopaedic residents should use fluently before encountering them in the operating room. A curriculum was designed to teach the foundation and component behaviors necessary to achieve fluency. The curriculum was composed of 16 modules and 72 sub-modules and was presented to the 2014 and 2015 PGY-1 orthopaedic residents during a 1-month dedicated rotation (July 2014 and July 2015). Upon completion of the first rotation, the six members of the 2014 PGY-1 class were asked to complete timed tasks to evaluate their skills. Both the 2014 and 2015 classes were asked to fill out a detailed survey evaluating the tool modules and the module instructors. The costs of the modules were recorded.

Results: All six members of the 2014 PGY-1 class completed all of their timed tasks. One resident did not successfully perform one of four knot tying tasks and another resident did not successfully perform a drill task. Twelve residents, (all six members of both the 2014 and 2015 PGY-1 classes) completed the survey. All of the 2015 class (6/6) considered themselves comfortable with at least half of the tools, and five of the six members of the 2015 class were comfortable with all of the tools. The survey also indicated that teachers successfully communicated the goals of the modules, gave clear instructions and contributed to the module's success. The total cost for the skills month, for six residents, was $11,730 ($122/resident/module).

Conclusions: A curriculum was designed to teach PGY-1 orthopaedic residents the foundation skills necessary to use 14 orthopaedic tools fluently. The objective of teaching the foundation and complex behaviors required to use the 14 selected tools was achieved. That goal was accomplished using a precisely defined curriculum in a supportive environment that enabled deliberate practice. It was done in a way that was cost-effective and easily reproduced at other academic institutions. However, it still must be determined if these acquired skills transfer to environments outside the laboratory.

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Each author certifies that his or her institution approved or waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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In an effort to satisfy the American Board of Orthopaedic Surgery (ABOS) requirement for a month-long orthopaedic skills rotation, programs often construct a skills curriculum that is procedurally based. As an alternative, we describe here a skills program that teaches individual tool skills to fluency (accuracy at speed) using instructional modules that are innovative, challenging, inexpensive, and when combined with an operant learning program, encourage deliberate practice.[1,2] Work hour regulations, time and work load constraints on surgeon teachers, minimally invasive surgery, and the decreasing tool skills that orthopaedic learners bring to a residency program make it essential that orthopaedic programs create a curriculum that targets the training of those specific

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skills.[3] To insure that those skills are acquired, the American Board of Orthopaedic Surgery (ABOS) now requires a 1-month rotation be added to the orthopaedic curriculum that is dedicated to orthopaedic skill training.[4] As part of the response to this challenge, surgical skills education has moved to the laboratory where residents can practice on models, cadavers, and computer simulators to better prepare them for the operating room experience.[3] It is common for skill curricula to be procedurally based and aimed at solving complex problems while attempting to emulate reality. Unfortunately, this can add to the learning challenge. When simulation realism (fidelity) is over-enhanced, the desired learning outcome may be missed as a result of cognitive and sensory overload.[5]

Recently, an operant learning methodology has been used in orthopaedic education to create precise skills (complex behaviors) by highly reinforcing a skill's component behaviors.[2] The component behaviors are then reconnected to form the desired, fluent, complex behavior. To accomplish this for an array of complex tool behaviors, it was necessary to design a curriculum and learning platforms that allowed for the foundation and component behaviors to be taught and reinforced.

The goals of this project were as follows:

1. Design training modules that were tool specific and focused on teaching and reinforcing the foundation and component behaviors needed to use tools considered essential for performing orthopaedic surgery.
2. Create training modules that were additive and allowed for the formation of the complex behaviors necessary to fluently use the tools in a variety of environmental circumstances.
3. Build modules that used inexpensive tools and substrates, were interesting and challenging, and supported repetition and deliberate practice.
4. Evaluate each module's performance and acceptance by the learners.

Methods

The Albert Einstein College of Medicine's Institutional Review Board approved testing and found the project exempt because of its use of normal educational practices. Fourteen faculty members of the Montefiore Medical Center Department of Orthopaedic Surgery identified 14 tools commonly used in orthopaedic surgery that they thought should be used fluently by a resident surgeon prior to using them in an operating room. The group identified the complex behaviors needed to use those tools and then delineated the foundation and component behaviors necessary to form those complex behaviors. Modules and their related sub-modules were designed to establish those formative behaviors. One sub-module for each tool was dedicated to delineating the "Rules for Tools" for that specific tool (Table 1). In that sub-module, the point of action (business end), grip and stabilization options, the controls, and the power source were identified. Sixteen, 4-hour, instrument-specific modules (the drill was used in three modules; as a drill, a screw driver, and as a reamer) were designed and pre-tested for performance with the 2013 PGY-1 class over a 6-month period (January to June, 2014). The 16 instrument modules and 72 sub-modules were then presented to the 2014 and 2015 PGY-1 classes during each class's 1-month orthopaedic skills rotation (July 2014 and July 2015). Each module and its sub-modules were supervised by a faculty member who was an expert in the skill's performance and who was involved in the development of that specific module.

For the suture module, small caliber cotton rope and 20-pound test Dacron fishing-line (Cabela's, Sidney, NE) were used for knot tying (Table 1). For the needle holder component of the module, a 7 inch Mayo-Hegar needle holder (Symmetry Surgical®, Antioch, TN) was used along with Martin's Uterine 1/2 Circle Reverse Cutting Richard-Allan® Needles (Aspen Surgical™ Products, Caledonia, MI), Dacron fishing-line, and baseballs with their stitching removed (Rawlings, St Louis, MO).

For the scissors module, Metzenbaum scissors, Adson forceps (Symmetry Surgical, Antioch, TN), and meat products (breast of veal, pig feet) were used. The materials used for practice for the chisel (Craftsman Studio, Millbury, MA), osteotome (Innomed Inc., Savannah, GA), rongeur and curette (Aesculap Inc., Center Valley, PA) modules, included soft wood, Masonite, butternut squash, pumpkins, and hard boiled eggs.

For the drill modules, 12-volt battery powered drill/drivers (DeWALT Industrial Tool Co., Baltimore, MD) and standard twist drill bits (DeWALT Industrial Tool Co., Ryobi Limited, Anderson, SC) were employed. For reaming activities, a multi-tool with a coupled driver head (Ridge Tool Co., Elyria, OH), acetabular reamers (Stryker Corp., Kalamazoo, MI), and cannulated reamers (Smith and Nephew, Inc., Andover, MA) were used. For the high-speed drilling modules, variable speed rotary tools (Dremel®, Robert Bosch Tool Corp., Mount Prospect, IL) were used. While PVC pipe was useful for most drilling projects, it did not have the 'feel' of bone and was not reliable for teaching plunge prevention. A "plunge stick" (a composite of 1"x 2" pine board glued to plywood) was developed, tested, and ultimately used for this purpose. The composite created the feel of cortical penetration. Deck screws of varying lengths were used for screw placement and fixation. A purpose-built material made from large pore sponges and plaster-of-Paris, "Spongebone," was designed, tested, and used for the reaming modules (Tables 1 and 2, Fig. 1). Eggplants were used to hide the PVC pipe for the "Blind" Drilling and the "Perfect-Circle" sub-modules. A mini-C arm borrowed from the Department of Orthopaedics clinical office was used for these sub-modules.

The saw modules used two sets of AC powered multi-tool oscillating saws (Craftsman/Sears Holdings, Hoffman Estates, IL and Ridge Tool Co.), an AC powered reciprocating saw (Ridge Tool Co.), a 12-volt battery powered reciprocating saw (DeWALT Industrial Tool Co.), and a cast-saw (Stryker Corp.). Two sets of oscillating and reciprocating saws were required because of overheating of the tools while completing the modules. One inch by two-inch and one inch by three-inch boards of untreated pine, along with PVC pipe of vary-

Table 1 The Tool Skill Curriculum

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
Saw 1 (cast saw)	Rules for tools (RFT)	Business end Grip possibilities Stabilization Controls Power	Cast saw
	Run cut	Grip Stabilize Locate Touch and go Rotate around blade	Eye and ear protection Cast saw 4″ PVC pipe Foam carpet padding 4″ Cast padding 4″ Fiberglass cast material
	Plunge cut	Grip Stabilize Locate Initiate Touch and go Oscillate around pivot Rotate around blade	Eye and ear protection Cast saw 4″ PVC pipe Foam carpet padding 3″ and 4″ Cast padding 3″ and 4″ Fiberglass cast material Eggplants
Saw 2 (oscillating saw)	RFT	Business end Grip possibilities Stabilization Controls Power	Oscillating saw
	Run cut	Grip Stabilize Locate Initiate Touch and go Oscillate around pivot Rotate around blade	Eye and ear protection Oscillating saw Clamps 3/8″ Plywood
	Plunge cut	Grip Stabilize Locate Initiate Touch and go Oscillate around pivot	Eye and ear protection Oscillating saw Vise 1″ x 2″ Pine board 1″ x 3″ Pine board "Spongebone"
	Flush cut	Grip Stabilize Locate Initiate Bounce blade Touch and go Oscillate around pivot	Eye and Ear Protection Oscillating saw Vise 45° and 90° Pine board jig 1″ x 3″ Pine board Deck screws for jig
Saw 3 (reciprocating)	RFT	Business end Grip possibilities Stabilization Controls Power	Reciprocating saw
	Push cut	Grip Stabilize Locate Initiate Push	Eye and ear protection Reciprocating saw Vise 1″x 2″ Pine board "Spongebone"
	Pivot cut	Grip Stabilize Locate Initiate Pivot Push	Eye and Ear Protection Reciprocating saw Vise "Spongebone" 1″ Hardwood dowel

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
Scissor	RFT	Business end Grip possibilities Stabilization Controls Power	Metzenbaum scissor
	Spreading	Grip Stabilize Gentle push Spread	Metzenbaum scissor Adson forceps Breast of veal Grapefruit wedges
	Cutting	Grip Stabilize Gentle push Spread Control open Rotate Advance Cut	Metzenbaum scissor Adson forceps Breast of veal Pig feet Grapefruit wedges
Suture and Needle Holder	RFT	Business end Grip possibilities (suture) Pinch Pinch palm up Fakey pinch Wrap Backside grab Mctwist Push Flick Grip possibilities (needle holder) Stabilization Controls Power	1/4″ Nylon rope 7-inch Mayo-Hegar needle holder Martin's uterine reverse cutting needle
	Square knot (two hand, dominant)	1/2 over 1/2 Pinch Rock Over Push to through Cross Pinch Rock Through	1/4″ Nylon rope 20-pound test Dacron fishing line
	Square knot (two hand, non-dominant)	1/2 over 1/2 Pinch Rock Over Push to through Cross Pinch Rock Through	1/4″ Nylon rope 20-pound test Dacron fishing line

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
	Square knot (one hand, dominant)	Under cross Wrap Fakey pinch Flick Backside grab Over cross Push to four Mctwist Backside grab Through	1/4″ Nylon rope 20-pound test Dacron fishing line
	Square knot (one hand, non-dominant)	Under cross Wrap Fakey pinch Flick Backside grab Over cross Push to four Mctwist Backside grab Through	1/4″ Nylon rope 20-pound test Dacron fishing line
	Locking, sliding knot	1/3 over 2/3 Wrap over and through Wrap to fakey pinch Maintain loop Behind over and through Dress and tighten	1/4″ Nylon rope 20-pound test Dacron fishing line
	Bowline	Make a hole going up Wrap a loop Maintain the loop Up through the hole Around the straight rope Down through the hole Tighten the hole	1/4″ Nylon rope
	Suture passing	Grip needle in middle 1/3 Push to enter at 90° Rotate with the curve Push to exit Grasp and supinate out	7-inch Mayo-Hegar needle holder Martin's uterine reverse cutting needle 20-pound test Dacron fishing line Suture scissor Baseballs with stitching removed
Drill 1 (drill)	RFT	Business end Grip possibilities Stabilization Controls Power	Drill 1/8″ Drill bit
	Dimple	Grip Locate Stabilize Spin at low speed and remove while spinning	Eye protection Drill 1/8″ Drill bit Vise 1″ x 2″ Pine board 3/4″ PVC round pipe 1 1/2″ PVC round pipe
	Drill hole	Grip Locate Stabilize Spin at low speed Complete the hole and remove while spinning	Eye Protection Drill 1/8″ Drill bit Vise 1″ x 2″ Pine board 3/4″ PVC round pipe 1 1/2″ PVC round pipe

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
	Low-angle drill hole	Make a dimple Angle the drill tip Drill the low angle hole and remove drill while spinning	Eye protection Drill 1/8″ Drill bit Vise 1″ x 2″ Pine board 3/4″ PVC round pipe 1 1/2″ PVC round pipe
	Plunge avoidance	Grip Locate Stabilize Spin at full speed Apply counter pressure with stabilizing hand Complete hole and limit excursion Remove drill while spinning	Eye protection Drill 1/8″ Drill bit Vise “Plunge sticks”
	Targeting to a blind exit (two person)	Make a dimple Approximate the blind target with finger Control left-right Assistant controls high-low Drill to target	Eye protection Drill 3/8″ Drill bit Vise 1″ Round dowel 3/4″ PVC round pipe
Drill 2 (screws)	RFT	Business end Grip possibilities Stabilization Controls Power	Ratcheting screwdriver Drill Phillips bit Deck screws Countersink
	Screw placement	Pilot hole Stabilize screw in hole Push screw to engage Insert clockwise Remove counterclockwise	Eye protection Ratcheting screwdriver Drill 1/8″ Drill bit Vise Phillips bit Deck screws 1″ x 2″ Pine board 3/4″ PVC round pipe
	Over drilling (sliding hole)	1) Pilot hole with 1/8″ drill bit Gently engage 3/8″ drill bit Initiate slowly Advance at full speed Advance half way and remove while drill is spinning 2) Drill half way with 3/8″ drill bit and remove while drill is spinning Engage and align 1/8″ drill bit Complete drill hole	Eye protection Drill 1/8″ Drill bit 3/8″ Drill bit Vise 1″ x 2″ Pine board
	Compression screw	Stabilize pieces to be joined Make a dimple Make a low-angle drill hole Perpendicular portion to be joined Make a proximal sliding hole Insert screw Advance screw with ratcheting screwdriver Compress joined pieces	Eye protection Drill 1/8″ Drill bit 3/8″ Drill bit Ratcheting screwdriver Vise 1″ x 1″ 45° Cut square dowels 1″ 45° Cut round dowel 3/4″ 45° Cut PVC round pipe

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
	Countersink	Make a drill hole Insert tip of countersink Initiate slowly Spin at full speed and apply gentle pressure with grip hand	Eye protection Drill 3/8″ Drill bit Countersink Vise 1″ x 2″ Pine board
Drill 3 (complex drilling)	Single hand drilling	Grip Locate Stabilize Drill hole Feel and hear drill deceleration and release pressure to avoid plunging	Eye protection Drill 1/8″ Drill bit Vise "Plunge sticks"
	Targeting to a blind exit (one person)	Make a dimple Approximate the blind target with finger Control left-right Control high-low Drill to target	Eye protection Drill 3/8″ Drill bit Vise 1″ Round dowel 3/4″ PVC round pipe
	Perfect circles	Align holes to perfect circles adjusting medial lateral (valgus-varus) Align holes to perfect circles adjusting top and bottom (proximal-distal) Overlay drill point at center/center Orient drill bit Advance drill bit	Eye protection Drill Long 3/16″ Drill bit Vise 3/4″ PVC pipe fixed inside predrilled 1 1/2″ PVC pipe Image intensifier Eggplant
Drill 4 (high speed)	RFT	Business end Grip possibilities Stabilization Controls Power	Variable speed rotary tool Vise 1″ x 2″ Pine Board
	Straight lines	Grip Stabilize Spin at full speed Touch to surface Move along line by ulnar deviating wrist and repositioning heel of hand Remove device before stopping	Eye protection Variable speed rotary tool Vise 1″ x 2″ Pine Board
	Circles	Grip Stabilize Spin at full speed Touch to surface Move along circle by adjusting pinch position and repositioning heel of hand Remove device before stopping	Eye protection Variable speed rotary tool Vise 1″ x 2″ Pine Board
	Keyholes	Cut a straight line with small cutter Deepen the line Cut a circle at one end with large cutter Deepen the hole with the large cutter Undercut both sides of the line	Eye protection Variable speed rotary tool Large high speed cutter Small high speed cutter Vise 1″ x 2″ Pine Board

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
	Cutting metal	Protect surrounding area with wet paper towel Eye protection Initiate at high speed Gentle pressure on disk perpendicular to metal to be cut Complete cut Remove cutting tool at full speed Metal is extremely hot, do not touch	Eye protection Variable speed rotary tool Brass screws Vise 1″ x 2″ Pine board Paper towels
Drill 5 (reamer)	RFT Acetabular reamer	Business end Grip possibilities Stabilization Controls Power	Drill Acetabular reamer
	Plunge reaming (gouging)	Grip Stabilize Stabilize stance Elevate elbow Locate Initiate Apply gentle vertical pressure Stop reamer in place	Eye protection Spray bottle with water (minimize dust) Drill Acetabular reamer
	Side reaming (scuffing)	Grip Stabilize Stabilize stance Elevate elbow Locate Initiate Pull and push side to side Stop reamer in place	Eye protection Spray bottle with water (minimize dust) Drill Acetabular reamer
	RFT Cannulated reamer	Business end Grip possibilities Stabilization Controls Power	Drill Cannulated reamer Guide pin
	Tunnel cutting	Insert guide pin Slide cannulated reamer over the pin Insure reamer slides with no resistance Start reamer spinning Engage "Spongebone" Gently advance Retrieve if reamer ceases to advance Ream to desired depth Retrieve while spinning Stay in line with the guide pin	Eye protection Drill Cannulated reamer Guide pin "Spongebone"
Arthroscope (diagnostic)	RFT	Business end Grip possibilities Stabilization Controls Power	Arthroscope Light cable Camera Cannula-Probe Grasper
	Insertion	Grip Locate portal Place obturator in portal Advance with forward pressure Continue to fixation bolt	Arthroscope Light cable Camera Cannula Obturator Grapefruit Holder Clamps

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
	Quadrant visualization	Insert cannula Remove obturator Connect light source to arthroscope Insert arthroscope Establish visual field Grip and balance arthroscope Stabilize by fixing elbow to body side Move arthroscope side to side with gentle hand motion	Arthroscope Light cable Camera Cannula Obturator Grapefruit Holder Clamps
	Forward and back	Visualize quadrant Stabilize position by fixing elbow Stabilize cannula with free hand Advance and retract with gentle arthroscope hand motion	Arthroscope Light cable Camera Cannula Obturator Grapefruit Holder Clamps
	Eyepiece rotation	Visualize quadrant Stabilize position by fixing elbow Grasp light cable junction with arthroscope with free hand and rotate eyepiece	Arthroscope Light cable Camera Cannula Obturator Grapefruit Holder Clamps
	Triangulation with probe	Visualize quadrant Stabilize position by fixing elbow Locate position of second portal Visualize outside grapefruit the location of the tip of the arthroscope Insert probe while watching from the outside Find probe on monitor and manipulate	Arthroscope Light cable Camera Cannula Obturator Probe Grapefruit Holder Clamps
	Grasper	Visualize quadrant Locate seed Triangulate with probe Triangulate with grasper Capture seed and remove	Arthroscope Light cable Camera Cannula Obturator Probe Grasper Grapefruit Holder Clamps
Arthroscope (manual tools)	RFT	Business end Grip possibilities Stabilization Controls Power	Straight biter Angled biter Suture passer Chisels Rasps
	Straight biters	Visualize quadrant Locate celery Triangulate with probe Triangulate with straight biter Turn biter to 45° Open biter mouth Advance to target on celery Bite Remove and repeat	Arthroscope Light cable Camera Cannula Obturator Straight biter Grapefruit Celery Holder Clamps

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
	Up biters	Visualize quadrant Locate celery Triangulate with probe Triangulate with up biter Turn biter to 45° Open biter mouth Advance to target on celery Bite Remove and repeat	Arthroscope Light cable Camera Cannula Obturator Up biter Grapefruit Celery Holder Clamps
	Suture passers	Visualize quadrant Locate carrot Triangulate with probe Triangulate with suture passer Locate Push Rotate Pass nitinol wire Remove passer	Arthroscope Light cable Camera Cannula Obturator Suture passer Grapefruit Carrot Holder Clamps
	Chisels	Visualize quadrant Locate carrot Triangulate with probe Triangulate with chisel Locate and orient Assistant advance chisel with mallet Wiggle or strike to remove	Arthroscope Light cable Camera Cannula Obturator Chisel Grapefruit Carrot Holder Clamps
Arthroscope (power tools)	RFT	Business end Grip possibilities Stabilization Controls Power	Arthroscopic shaver system Drill K-wire
	Arthroscopic shaver system	Insert arthroscope Create ancillary portal Triangulate shaver to carrot Initiate shaver Apply gentle force against carrot Advance with side to side motion Stop shaver and remove	Arthroscope Light cable Camera Cannula Obturator Shaver system Grapefruit Carrots Holder Clamps
	Drill	Insert arthroscope Create ancillary portal Triangulate clear cannula to carrot Leave small space between cannula and carrot Pass K-wire down plastic cannula Locate K-wire on target Advance K-wire Remove K-wire while still spinning	Arthroscope Light cable Camera Cannula Obturator Drill K-wire Clear cannula Grapefruit Carrot Holder Clamps

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Table 1 *Continued*

Tool Module	Sub-modules	Foundation and Simple Behaviors	Materials
Osteotome	RFT	Business end Grip possibilities Stabilization Controls Power	Chisel Osteotome Mallet
	Straight chop	Grip Locate Strike and initiate Strike and propagate Strike and rotate	Chisel Mallet Bar clamps 1″ x 2″ Pine board
	Circular chop	Grip Locate Strike and initiate Strike and propagate	Chisel Mallet Bar clamps 1″ x 2″ Pine board
	Paring	Grip Locate and place chisel nearly parallel to stock Load chisel blade with downward force of stabilizing hand Oscillate grip hand while gently moving forward Twist grip hand to remove material	Chisel Bar clamps 1″ x 2″ Pine board
	Mortise cuts	Straight chop x 4 Pare material within boundaries Repeat to desired depth	Chisel Mallet Bar clamps 2″ x 4″ Pine board
Rongeur and Curette	RFT	Business end Grip possibilities Stabilization Controls Power	Rongeur Curette
	Rongeur front bite	Grip Load halfway Close with power Bend and remove	Rongeur 1/8″ Masonite Butternut squash
	Rongeur side bite	Grip Load halfway Close with power Bend and remove	Rongeur Masonite
	Rongeur rip	Grip Load Close Twist	Rongeur Foam carpet padding
	Curette	Grip Side cup Scrape Remove	Curette Butternut squash Hard-boiled egg
Compartment Pressure Monitor	RFT	Business end Grip possibilities Stabilization Controls Power	Stryker intra-compartmental pressure monitor
	Monitor pressure	Assemble needle, chamber, and syringe Place assembly into housing Flush assembly Zero the device at insertion angle Insert needle into saline bag Tap plunger and inject less than 0.3 cc Read pressure	Stryker intra-compartmental pressure monitor Oranges 20 cc Syringe 21-gauge needle 50 cc IV saline bag Blood pressure cuff

Table 2 Making "Sponge Bone"

Materials
- Polyurethane sponges are 19 cm L X 14 cm W X 5 cm H (7 ½" X 5 ½" X 2") (QEP Co., Inc., Boca Raton, FL).
- Plaster of Paris (DAP Products Inc., Baltimore, MD).

Equipment
- 31-quart Tandem™ mop bucket (Rubbermaid, Winchester, VA).
- 19 cm mixing spoon (Bradshaw International Inc., Rancho Cucamonga, CA)
- Hand-held electric mixer (Sunbeam Products Inc., Boca Raton, FL)
- Neoprene gloves for handling sponges during preparation (Big Time Products, Rome, GA, item No. 24102).
- Polypropylene bin, 38 cm L X 36 cm W X 19 cm D (16 ½" X 14" X 7 ½") (Sterilite Corp., Townsend, MA).

Methods

Eight liters of cold tap water were added to the reservoir section of the mop bucket. Four polyurethane sponges were placed in the reservoir section and completely immersed in the water. Each sponge was squeezed by hand beneath the surface of the water to allow total saturation of the sponge. Following saturation, sponges were placed one at a time in the wringer, and water was wrung out three times. After wringing out, sponges were set aside.

A waste bucket was prepared by lining it with two trash can liners. Surgical mask and gloves were worn during the remainder of the preparation procedure. Three liters of cold tap water were added to the polypropylene preparation bin. Plaster of Paris powder was measured out by volume. The 3.6 liters of Plaster of Paris was carefully added at one time to the cold tap water, taking care to generate as little dust as possible (see MSDS for Plaster of Paris). The Plaster of Paris was mixed into the water using a plastic spoon for 30 seconds. Care was taken to submerge all of the powdered material. Mixing was continued using a hand-held electric mixer, set on speed #2, for 1.5 min. The slurry was checked for lumps using gloved hand and then mixed for an additional 1 min.

The sponges were placed into the plaster in the preparation bin and pressed down on to completely absorb the slurry. Each sponge was pressed down on again to expel slurry and reabsorb it, so that all void spaces in the sponge were filled with slurry. The expulsion and absorption was repeated a third time. All the sponges were turned over, and the expulsion and absorption step was repeated three times. The sponges were turned over a third time, and the expulsion and absorption step was repeated three times. The sponges were turned over a final time and allowed to fully coat with slurry. They were removed one at a time, taking care not to squeeze them out during the removal process. They were then placed on the lid of the preparation bin. The remaining excess slurry was immediately discarded from the preparation bin into the waste bucket (do not dispose of excess plaster slurry in sink). The equipment was washed with water, and caked plaster discarded in a waste bucket. Solidified waste plaster was then discarded in a sealed waste bag with regular trash.

Sponges were allowed to dry out at room temperature in a dry, well ventilated location for at least 72 hours.

ing diameters were used for the saw modules. "Spongebone" was also used in these modules. The cast saw module used fiberglass-casting material and cast padding placed over 4" PVC pipe covered with carpet under-padding. Eggplants covered with fiberglass-casting material and cast padding were also used in the cast saw module (Table 1, Fig. 2).

Video, hand, and power equipment for the arthroscopy modules were loaned or donated by the manufacturers (Stryker Corp. and Smith and Nephew, Inc.). Arthroscopy modules used grapefruits as a practice medium. Celery and carrots were placed in the grapefruits for practice with hand and power instrumentation as well as for suture placement (Table 1, Fig. 3). Small vacuum pumps (Medline Industries, Inc., Mundelein, IL) were available to maintain a dry working field.

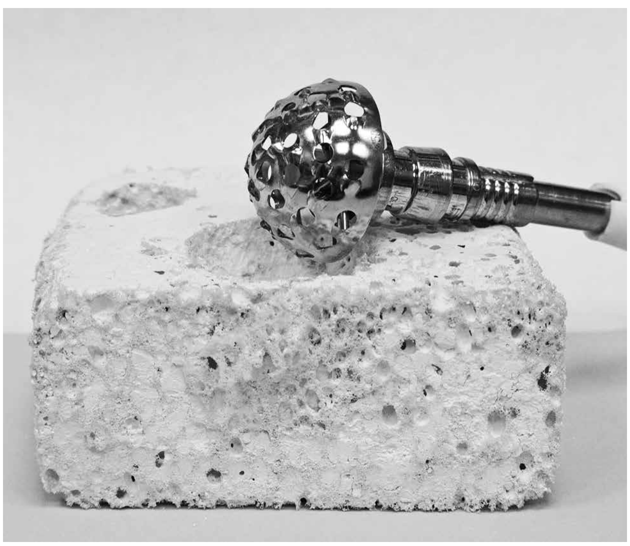

Figure 1 "Spongebone" is a purpose-built material made from large pore sponges and plaster-of-Paris and was used with the reaming and saw modules.

Figure 2 Eggplants were covered with fiberglass-casting material and cast padding and were used in the cast saw module.

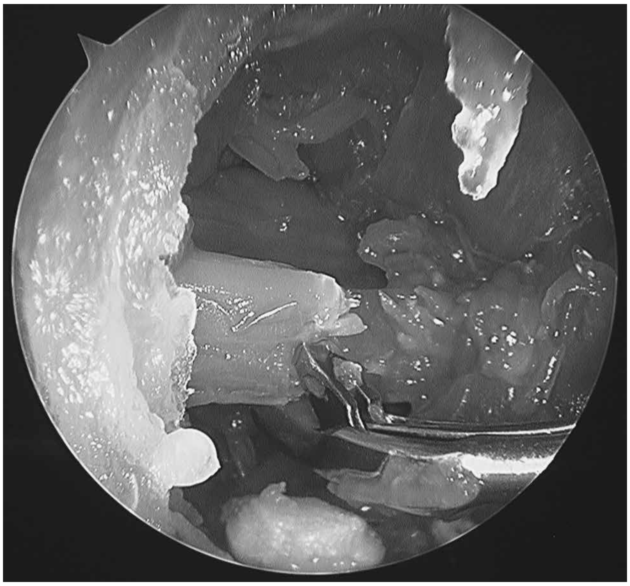

Figure 3 Grapefruits were used as a practice medium for the arthroscopy modules. Celery and carrots were placed in the grapefruits for use with hand and power instruments.

Compartment pressure monitors (Stryker Corp.) were deployed on oranges and standard intravenous saline bags as recommended by the ABOS.[6]

All of the module curriculums emphasized positive reinforcement of foundation and component behaviors.[2] At the end of each module, the residents were asked to complete projects that required each resident to apply the learned behaviors to more challenging situations. Weekly practice and project sessions were directed, observed, and coached by the curriculum director (IML).

At the end of the orthopaedic skills rotation, the PGY-1 participants were given a task oriented final exam and an anonymous survey (Tables 2 and 3). In this survey, the participants were asked to evaluate their experience, the teaching methods, the instructors, and each of the modules. The faculty was asked to evaluate their specific module.

The cost of each module was recorded, and materials were divided into reusable (tools and accessories), replaceable (drill bits and blades), and disposable (wood, PVC tubing, and vegetables) items. Costs were tabulated for the entire skills month along with individual reusable, replaceable and disposable total cost. A reusable, replaceable, and disposable averaged cost per module was determined. Using the total costs, a cost per module per student was calculated. The cost of the room itself was not considered in the calculation as it was pre-existing, and we determined that all of the modules could be completed in non-dedicated facilities.

Results

Observations by the learners and faculty indicated that the materials used for the modules were effective, and the modules and sub-modules were challenging. The meat products (specifically breast of veal) were an excellent substrate for the scissor sub-modules. Dacron fishing-line had the stiffness of suture without the cost. The baseballs proved valuable for targeting with a needle. PVC pipe of varying diameters, untreated pine board, and "plunge sticks" were excellent drill sub-module substrates. "Spongebone" was an inexpensive and worthwhile material for the acetabular reaming module. Saw related behaviors were easily acquired using pine board, plywood, PVC pipe, and Spongebone. Casts placed on eggplants were used to evaluate plunging with cast saws and were very effective for both instruction and evaluation. Pine board and butternut squash were effective substrates for the hard tissue instrument (osteotome, rongeur, and curette) modules. Grapefruits made for an effective and challenging arthroscopy training model. Carrots and celery placed within the grapefruits allowed for arthroscopic hand and power instrument practice.

All six members (three males and three females) of the 2014 PGY-1 orthopaedic surgery class and all six members (six males) of the 2015 PGY-1 class participated in all 16 modules during their respective orthopaedic skills rotation. All six members of the 2014 PGY-1 class completed the final exam tasks. One member of the class was unsuccessful at one knot tying task and another member did not successfully perform the plunge board test (Table 3). All six members of the both PGY-1 (2014-2015) classes filled out the anonymous survey (Table 4). Results of the survey indicated that for July of 2014 and 2015 teachers clearly communicated the goals of the modules 77% (2014) and 100% (2015), gave clear instructions 85% (2014) and 100% (2015), and contributed to the success of the module of 85% (2014) and 100% (2015) of the time. When asked about where they had achieved a "comfort level," the reamer, cast saw, and arthroscope remained challenging at end of the skill module, for both years. For the 2014 group, the osteotome and rongeur modules were not considered valuable. For the 2015 class, the acetabular reamer and the pressure modules were not considered valuable. Both groups asked for more time with the cast saw and oscillating saw. All 12 participants would recommend the skills laboratory to others, wanted to participate in future teaching sessions, and would like refresher modules to be offered.

A wide range of inexpensive materials were used for the sub-modules. The total, one time, fixed equipment costs for all 16 modules was $10,032 ($1,672/resident, $627/module) and $105/resident/module. The total, replaceable equipment (bits, blades, etc.) cost was $774 ($129/resident, $48/module) and $8/resident/module. The total, disposable items cost was $924 ($154/resident, $58/module) and $9/resident/module. The total cost for the skills month was $11,730 ($1,955/resident, $733/module) and $122/resident/module.

Discussion

The ABOS now requires all residency programs to incorporate orthopaedic skills training into their PGY-1 educational curriculum.[4] While surgical skills can be trained or enhanced with models, cadavers, or simulators in the laboratory setting, it is not clear that these measures improve performance in the operating room.[7] In addition, the models, simulators, and cadaver specimens used in the laboratory can be expensive and often use resources that are limited. This can result in an experience that is

Table 3 Final Exam Tasks Give to the 2014 PGY1 Class

Task	Time Average (sec)/SD	Number/Total Number Attempted
Right hand square knot Criteria: 10 successful knots	67.9/22.8	60/60
Left hand square knot Criteria: 10 successful knots	46.4/10.5	60/60
Knot in a bucket Criteria: 10 successful knots	90.6/15.0	60/60
Locking, sliding knot Criteria: 10 successful knots	83.1/16.8	50/60
Cast saw on eggplant Criteria: complete cut through cast, no injury to eggplant	139.7/58.2	6/30 complete cuts in fiberglass 22/30 partial cuts in fiberglass 1/30 eggplant cut
Pattern cut with scissor Criteria: cut 10 patterns accurately	132.7/41.2	60/60
Plunge board Criteria: Drill bit penetrates plywood, sheetrock, plywood, and foam but not third piece of plywood x 10.	123.5/24.7	Successful: 25/60 Dimple in third board: 21/60 Full penetration of third board: 14/60
Blind target Criteria: start 8 drill holes evenly distributed on clock face and exit out blind target.	242.8/64.9	In tunnel: 4/30 1/2" from target: 16/30 5/8" from target: 8/30 3/4" from target: 9/30 1" from target: 11/30
Saw one limb of tuning fork Criteria: Saw off three slices with no corner fractures and no scuffs or cuts on second limb.	145.1/40.1	Corner fractures on first limb of tuning fork: 2/18 Scuffs on second limb: 5/18 Cuts in second limb: 2/18
Tunnel with cannulated reamer Criteria: Complete tunnel in 1 minute; do not advance or remove guide pin.	6 tunnels completed, no guide pins advanced, 1 removed.	
Box graft with chisel Criteria: Cut box graft with chisel measuring 10 mm x 20 mm x 10 mm in 2 minutes	Width mm Mean/SD: 9.7/0.5 (6 grafts)	Length mm Mean/SD: 20.3/0.5 (6 grafts) Depth mm Mean/SD: 4.5/1.26 (6 grafts)

more effective at attaining familiarity with a complex task than it is at achieving fluency.[1,8] There is a viable alternative.

The goals of this project included developing an innovative and inexpensive modular curriculum that enhanced the learning of PGY-1 orthopaedic residents' tool skills, enabled the use of an operant learning methodology, and because of its low cost, allowed for significant practice.[2] The curriculum presented here accomplished those goals. The foundation, component, and complex behaviors necessary to use common orthopaedic tools were successfully taught. The learning platforms were inexpensive and adaptable to a variety of learning environments and could be modified for use by other surgical or invasive medical sub-specialties. The modules were well received by the learners.

We have previously shown that behavioral fluency can be achieved when the modules in this curriculum are combined with an operant learning methodology.[2] While our experience and the experiences of others suggest that curricula like the one presented here can be effective, it has not been shown that the learned behaviors reliably transfer to other environments.[7] We still need to demonstrate that those learned behaviors can be performed in the operating room. This is an important limitation of this project.

Another limitation of this study is that we have not firmly established a definition of fluency for each of the tools. While the accuracy of performance could be easily quantified, there were no well-defined times determined for fluent performance. One solution is to measure the accuracy and speed of a group of instructors and determine if there is definable performance ceiling.

We have described a skills program that teaches individual tool skills to fluency using instructional modules that are not procedurally based; are innovative, challenging, and inexpensive; and when combined with an operant learning program, encourage deliberate practice. While we are optimistic about the early results of the curriculum, we cannot determine the entire impact of this program until our test learners progress in their training.

Table 4 The 2014-2015 Survey and Results

		Yes 2014/2015	Somewhat 2014/2015	Not really 2014/2015	Response 2014/2015
Did teachers clearly communicate goals of module? (2014/2015)	Cast saw	6/6			6/6
	Scissor	5/6	1/0		6/6
	Suture	6/6			6/6
	Needle holder	6/6			6/6
	Drill	6/6			6/6
	Screw	6/6			6/6
	Complex	6/6			6/6
	Reamer	6/6			6/6
	Arthroscope	6/6			6/6
	Oscillating	6/6			6/6
	Reciprocating	6/6			6/6
	Osteotome	3/6	3/0		6/6
	Rongeur	5/6	1/0		6/6
Did the teachers give clear instructions? (2014/2015)	Cast saw	6/6			6/6
	Scissor	5/6			6/6
	Suture	6/6			6/6
	Needle holder	6/6			6/6
	Drill	6/6			6/6
	Screw	6/6			6/6
	Complex	6/6			6/6
	Reamer	6/6			6/6
	Arthroscope	6/6			6/6
	Oscillating	6/6			6/6
	Reciprocating	6/6			6/6
	Osteotome	3/6	3/0		6/6
	Rongeur	6/6			6/6
Did the teachers contribute to the success of the module? (2014/2015)	Cast saw	6/6			6/6
	Scissor	6/6			6/6
	Suture	6/6			6/6
	Needle holder	6/6			6/6
	Drill	6/6			6/6
	Screw	6/6			6/6
	Complex	6/6			6/6
	Reamer	6/6			6/6
	Arthroscope	6/6			6/6
	Oscillating	6/6			6/6
	Reciprocating	6/6			6/6
	Osteotome	5/6	1/0		6/6
	Rongeur	6/6			6/6
Consider the teacher you found most effective. Why? Check all that apply. (2014/2015)	On time and participated 2014/2015	Clear and easy to understand 2014/2015	Attentive, helpful, respectful 2014/2015	Other (specify*) 2014/2015	
	83%/100%	67%/67%	83%/83%	33%/16%	
What module did you enjoy the most?	1st	2nd	3rd	4th	
	Arthroscopy/14 Drill/15	Drill/14 Saw/15	Oscillating/14 Suture/15	Cast saw/14 Arthroscope/15	
Did you achieve comfort level with specific tools? Which ones?	100%	80%	60 %	40%	20%
	Suture/2014 Drill/2014 Drill/2015 Saw/2015 Suture/2015 Scissor/2015 Osteotome/2015	Saw/2014 Stryker pen/2014 Stryker pen/2015 Reamers/2015 Cast saw/2015 Arthroscope/2015	Cast saw/2014	Arthroscope/2014	Reamer/2014

(Continued on next page)

Table 4 Continued

Was any module a complete waste of time?	Module	Response		
	Osteotome/2014	3 of 6/2014		
	Rongeur/2014	3 of 6/2014		
	Reamer/2015	2 of 6/2015		
	Stryker pen/2015	3 of 6/2015		
Which refresher modules would you like made available? Check all that apply.	Module	Response %/year		
	Cast saw	50/2014	40/2015	
	Scissor	66/2014		
	Suture	0/2014		
	Needle holder	0/2014		
	Drill	33/2014	20/2015	
	Reamer	66/2014	20/2015	
	Arthroscope	66/2014	20/2015	
	Oscillating	50/2014	60/2015	
	Reciprocating	50/2014		
	Osteotome	33/2014		
	Rongeur	17/2014		
	Stryker pen	17/2014	40/2014	
Questions about your overall experience: 2014/2015	Yes	Sometimes	Not really	Response
Did the schedule work for you?	4/6	1	1	6/6
Did teaming up in pairs work for you?	6/6			6/6
Did you learn from your pair partners?	6/6			6/6
Did you find your fellow students congenial and helpful?	6/6			6/6
	Yes	Maybe	No	Response
Would you recommend this kind of skill lab to others?	6/6			6/6
Would you ever like trying to teach a module or two?	6/6			6/6
Would you like to see refresher modules or mini-modules?	6/6			6/6

Conflict of Interest Statement

During the study period, the institution of three authors (IML, EDF, JFS), Montefiore Medical Center, received research funding from the American Board of Orthopaedic Surgery and the OMeGA Medical Grants Association. One author (TRK) is an employee of TAGteach International. One author (KWP) is a retired employee of Karen Pryor Clicker Training. The authors declare no competing interest.

References

1. Binder C. Behavioral fluency: evolution of a new paradigm. Behav Anal. 1996 Fall;19(2):163-97.
2. Levy IM, Pryor KW, McKeon TR. Is teaching simple surgical skills using an operant learning program more effective than teaching by demonstration? Clin Orthop Relat Res. 2016 Apr;474(4):945-55.
3. Reznick RK, MacRae H. Teaching surgical skills-changes in the wind. N Engl J Med. 2006 Dec 21;355(25):2664-9.
4. American Board of Orthopaedic Surgery. 2016 rules and procedures for residency education Part I and Part II examinations. Available at: https://www.abos.org/media/13762_rules_and_procedures_-_part_ii.pdf. Accessed October 23, 2015.
5. Chauvin S. Applying educational theory to simulation-based training and assessment in surgery. Surg Clin North Am. 2015 Aug;95(4):695-715.
6. American Board of Orthopaedic Surgery. ABOS surgical skills modules for PGY-1 Residents. Available at: https://www.abos.org/abos-surgical-skills-modules-for-pgy-1-residents.aspx. Accessed October 23, 2015.
7. Atesok K, Mabrey JD, Jazrawi LM, Egol KA. Surgical simulation in orthopaedic skills training. J Am Acad Orthop Surg; 2012 Jul;20(7):410-22.
8. Lopez G, Wright R, Martin D, et al. A cost-effective junior resident training and assessment simulator for orthopaedic surgical skills via fundamentals of orthopaedic surgery: AAOS exhibit selection. J Bone Joint Surg Am. 2015 Apr 15;97(8):659-66.