Psychomotor Skills for the 21st Century: What should students learn?

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Introduction

It is widely recognized that technology is changing the world of work.¹ With advances continuing at a rapid pace, there is a mixture of excitement and fear: changes such as automation, artificial intelligence, and robotics propel our economy forward, while simultaneously displacing workers.² At the time of writing, robots are beginning to surpass perceived limitations in dexterity and learning, becoming more human-like in their capabilities.³,⁴ A working paper from the National Bureau of Economic Research reports that each additional robot per thousand workers reduces employment by 3 to 5.6 workers and aggregate wages by about 0.25 to 0.5 percent, with the low-ends being in industries that are most exposed to robots.⁵ McKinsey Global Institute estimates that by 2030, 30 percent of work in 60 percent of occupations could be automated.⁶

While automation and other technological advancements will undoubtedly shape the future of work across sectors, fear that robots will replace humans have so far been misplaced. In fact, “despite extensive automation since 1950, it appears that only one of the 270 detailed occupations listed in the 1950 Census was eliminated thanks to automation – elevator operators;”⁷ and, in fairness, one can still find elevator operators in New York City. The critical point is that the numbers employed in any given occupation might be severely impacted by technology as the modernization of society will render some jobs obsolete and push others to evolve. Neither blue collar nor white collar jobs are immune to the effects of technological advancements. Everything from manufacturing to bookkeeping to driving is impacted by technology,⁸ and the advent of new and improving technologies will require re-training and re-distribution of work across industries and occupations.

In our earlier publication, Skills for the 21st Century⁹, we identified and discussed the cognitive skills students need to thrive in today’s society. In this report, the focus is on the psychomotor skills necessary for success in work and life. To best prepare students for this changing world, it is most useful to ask: what psychomotor skills are least likely to be replaced by technological advancements? And, what psychomotor skills are needed to thrive in this continuously evolving,
increasingly technological world of work? This paper will justify and explore the Psychomotor Skills necessary for a 21st Century Education, identifying two “meta-motor” abilities as essential: coordination and adaptation.

In crafting this synthesis and proposed framework for thinking about motricity, we reviewed literature from a variety of fields such as education, child development, medicine, sports, workforce development, and the arts. Much of this literature on psychomotor skills is subject and/or occupation bound. While there is information on how to develop psychomotor skills more generally and how to measure their performance more specifically, there is a dearth of research when it comes to identifying universally critical ways of describing psychomotor skills.

This paper proposes a new way of thinking about motricity. To facilitate this discussion, one must first revisit traditional classifications of psychomotor skills.

### Taxonomy for psychomotor learning

#### Traditional Classifications

The most common classification of psychomotor skills is “gross” and “fine.” Gross motor skills are defined as those that involve larger groups of muscles (for example, arms or legs), while fine motor skills are those that involve smaller groups of muscles such as those found in fingers. Within these two broader categories of psychomotor skills there are countless context- and job- specific skills to master, such as: assembling parts, operating controls, putting in an IV, using a scalpel, typing, reaching, lifting, and walking.

In practice, most movements require a combination of gross and fine motor skills. Even writing, often identified as a fine motor skill, additionally requires coordination of larger muscle groups in the arm. Consequently, present classifications of skills as either gross or fine, rely on an overly simplistic dichotomy. While acknowledging the advantages of the job-requirement approach used by the used by Programme for the International Assessment of Adult Competencies (PIAAC) and The Occupational Information Network (O*NET) to assess psychomotor skills, it is also of note that these popular data sets rely on the fine/gross motor skill dichotomy and thus focus their assessment on vague sub-categorizations of movement (e.g., physical v. skilled manual tasks), missing the complexity inherent in psychomotor skills.

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While Bloom’s Taxonomy identifies Psychomotor as one of three domains of educational activities, the committee that created it failed to provide a progression for development of these skills, noting lack of expertise in the area. Others have filled this gap, proposing their own taxonomies for thinking about the development of psychomotor skills.

Review of work on development of psychomotor skills revealed some confounding factors. Existing progressions posit a linear way of thinking about the development of a skill; however, they tended to describe performance measures (e.g., precision or stamina) as well as higher level coordination and/or adaptation of skills as unique developmental stages. We argue that doing so confounds multiple aspects of psychomotor learning, forcing activities that develop on parallel tracks to be conceived of on a singular track.

On the scale of development of a single skill, one simple way to conceptualize learning comes from the conscious competence model (Figure 1). Two factors are relevant in this model: conscious awareness and degree of competence. In the first stage, Unconscious Incompetence, the goal is not conceptualized, and so they can’t properly use feedback. In other words -- if one doesn’t know what it feels like to be balanced, then one doesn’t know how to work toward being balanced.

Once a learner becomes aware of the goal, they become aware of their own incompetence. With practice, they can become competent (defined by many different measures, as we’ll discuss below), but it will take conscious attention to the task. With even more trial and error practice, the competence becomes unconscious. This unconscious competence can become part of a different skill’s unconscious incompetence when a new aspect is involved, for example, one can unconsciously and

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19 These stages line up with the way other psychomotor frameworks have described various stages. For example, unconscious competence has been described as Naturalization, everything unconscious has been described as reflexive, and everything conscious as reactive.

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Figure 1: Conscious Competence model  
Source: Adapted from Cannon et al 2014

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competently keep rhythm, but fail to realize that they lose the rhythm on the offbeats. The development of this new skill (or transfer of an old skill, depending on how one wants to categorize it based on the larger goals) begins with becoming aware of the unconscious incompetence built on the previous skill’s unconscious competence. One can then move through the entire progression with this new yet related skill.

Feedback for psychomotor learning: Perception and proprioception

Typically found early on in psychomotor progressions as precursors to more advanced stages of movement, perception and proprioception are identified herein as critical aspects of a feedback loop in motricity, not developmental stages unto themselves as some\(^{20}\) \(^{21}\) have claimed. Perception is awareness gained through the five senses (sight, hearing, smell, taste, and touch). Proprioception refers to one’s awareness of their body in space.\(^{22}\) In order to develop in any given skill, one needs the ability to receive, interpret, and ultimately act on perceptive or proprioceptive input, creating a feedback loop that facilitates the refining of movement.\(^{23}\) In this sense, perception and proprioception are not specific steps in the development of psychomotor skills, rather they are continuous mechanisms for feedback\(^{24}\), which is necessary to refine one’s psychomotor skills and facilitate transfer of these learned skills to new domains.\(^{25}\) In other words, they create the conditions necessary for trial and error to take place, so that one may move from unconscious incompetence through unconscious competence. In the highest level, perception and proprioception are key in coordinating movement, as conscious awareness plays less of a role, and movement is determined based on input.

Measures of Motor Skills

To have productive discussions about motricity and how to best facilitate psychomotor learning, it is critical to move beyond the status quo’s simplistic dichotomy of gross and fine psychomotor skills, toward thinking about motor skills in general as laying on several continua that correspond to various dimensions of performance relevant to the task at hand. Doing so emphasizes the inherent complexity of movement and the important role measurement plays in defining and categorizing skills.

As outlined in the table below, measures of psychomotor performance found across many frameworks include attributes such as precision, accuracy, speed, and consistency, as well as physical abilities such as strength, flexibility, balance, and stamina. These metrics can be used to assess development of psychomotor skills within and across jobs, placing individuals on a set of performance continua uniquely weighted to reflect the task at hand. For instance, tightening a screw would be high on precision whereas moving a box would rank low.

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24 In some cases, it may be more accurate to discuss “feed-forward” systems
<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision</td>
<td>Degree of exactness</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Achieving intended outcome</td>
</tr>
<tr>
<td>Speed</td>
<td>Time to achieve outcome</td>
</tr>
<tr>
<td>Strength</td>
<td>Power to move objects and/or perform physically demanding tasks</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Range of motion</td>
</tr>
<tr>
<td>Balance</td>
<td>Maintaining stability (static and dynamic)</td>
</tr>
<tr>
<td>Stamina</td>
<td>Sustaining physical effort</td>
</tr>
<tr>
<td>Consistency</td>
<td>Parameters above, over time</td>
</tr>
</tbody>
</table>

Table 1: Measures of psychomotor skill, from across sources
Source: CCR

Meta-motor abilities

So far the discussion has focused on the development of a single motor skill. In practice, however, it can be quite difficult to separate complex skills and their various dimensions. For instance, one may be quite adept at running—perhaps it is second nature—but cannot run and dribble a basketball. Running and dribbling a basketball are two separate skills, at which one may be at different levels developmentally. The level of competence in one is irrelevant to level of competence of the other.

Like perception and proprioception, coordination and adaptation are not stages in the development of a psychomotor skill, but rather reside outside of, and apply across, that general progression. Whereas perception and proprioception are feedback mechanisms, coordination and adaptation are meta-motor skills, since they can apply to skills that have been developed to various levels of proficiency.

Coordination

Combining psychomotor skills can happen within a given time (such as running and dribbling a basketball) or it can happen across time (such as sequencing together the skills involved in building a car engine). Assembling, typing, styling hair, and even more simple tasks such buttoning or zipping clothing all require a degree of coordinated movement. The capacity for coordinated movement allows us to create patterns of movement to achieve a desired result. This is a critical skill in

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everything from surgery to dance. As discussed above, perception and proprioception play a critical role here in providing feedback.

Recent advances have demonstrated significantly improved coordination in robots, an area that has been a pain point in development. Within the context of automation and robotics, coordination (and, particularly hand-eye coordination) is especially difficult, and critical to future progress. Perception and manipulation have previously been identified as bottlenecks in development, more specifically the precisely coordinated movement of fingers is an area in which humans retain the competitive advantage. More broadly speaking, our ability to say, climb a ladder while carrying equipment that will then be used to install solar panels is an example of coordination that has been difficult for our technological counterparts to replicate. These “non-routine” tasks, which do not rely on explicit instructions, require greater coordination (in terms of sequencing) and also adaptation (covered in the next section), and are among those that, despite gains in dexterity, are less likely to be replaced by technology in the near future.

**Adaptation (aka Transfer)**

Psychomotor skills, like cognitive skills, require the ability to transfer skills to different contexts. The context a skill is learned in and the context it must be transferred to may be near (share many features in common), or far (share fewer or deeper features in common). Change is also not unilinear. There are various dimensions that can be changed about the context, such as the environment the task must be performed in, the criteria of particular aspects of the task, and the medium involved. The table below shows three types of changes to context that necessitate transfer, and examples of corresponding near and far transfer tasks. These types are not exhaustive nor are they mutually exclusive.

<table>
<thead>
<tr>
<th>Near Transfer</th>
<th>Far Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environment</strong></td>
<td><strong>Environment</strong></td>
</tr>
<tr>
<td>building a circuit in a lab → building a circuit on a ladder</td>
<td>building a circuit in a lab → building a circuit on a ladder in the rain</td>
</tr>
<tr>
<td><strong>Criteria</strong></td>
<td><strong>Criteria</strong></td>
</tr>
<tr>
<td>picking up a box once → picking up a box 5 times</td>
<td>picking up a box → picking up a box 50 times</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td>typing on a computer → typing on a tablet</td>
<td>playing piano → playing the flute</td>
</tr>
</tbody>
</table>

**Table 2: Near and Far Transfer**

*Source: CCR*

When considering the difficulty of transfer, it is important to consider both how many factors are varied, and how much they’re varied. For example, learning to play the flute after having learned the

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**Psychomotor Skills for the 21st Century**

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piano, one may be able to appreciate differentiation of sound production in fingering, but have difficulty with the motor skills involved in embouchure.

Within the context of automation and robotics, transfer is especially critical as creating perceptive/proproprioeptive feedback loops for robots is exceptionally difficult -- this again invokes routine versus non-routine tasks. Routine tasks are easily programmed, but do not account for changes in environment. Sensory input is critical to transfer as it allows one to adjust their movement to meet the specific requirements of a situation.

Take for instance, another engineering bottleneck that has been identified: working in cramped spaces and/or awkward positions. Perhaps one knows how to install a lightbulb. Can they get into a crawl space and install a lightbulb, with limited room to move about, perhaps in a reclined position, and dim lighting? To achieve that non-routine task requires transfer. Being adept at navigating environmental demands is critical to effectively operating in the 21st century, and “varying just one aspect of a motor task—the size of an object, the height, slope, or texture of a surface—requires adaptation (transfer) of movements to conform to new environmental conditions.”

Far transfer, for instance being able to more easily learn to play the flute because one is trained at the piano, is additionally critical because as the world of work continues to evolve and be shaped by technology, the ability to transfer one’s psychomotor skills to fulfill new job functions is essential. The change will in many cases be akin to going from being able to perform heart surgery to being able to perform robotically-assisted heart surgery.

Meta-Motor Development

Similar to motor skills, meta-motor abilities can also move through a learning progression. One can be unconscious of their inability to combine skills, they can become conscious, they can become capable, and they can become unconsciously capable. Likewise, both coordination and adaptation can be measured according to attributes outlined in the preceding section. In essence, motor skills and meta-motor abilities operate the same way. The critical difference is that “meta-motor” indicates an additional combination or nuance to the skill.

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A typical complex coordinated skill progression may involve breaking the skill down into smaller skills, developing them to some degree of conscious competence, and then combining them and developing the coordinated skill. For example, in learning a piano composition, one must first learn each hand separately, and then put them together (that is, before they reach unconscious competence sight reading). Similarly, a typical way of developing a task that must be versatile would be to develop it in one context until it reaches a degree of conscious competence, and then begin developing it in other contexts. Thus, measures apply to psychomotor skills as well as meta-motor abilities.

**Conclusion**

Psychomotor skills represent “How we use our motricity.” Some degree of motricity is required to function in society at the most basic level. As our economy continues to evolve and technology advances, we will continue to observe shifts in what psychomotor skills are demanded by employers and for future success. Meta-motor abilities are likely to withstand these shifts. In other words, while the base “motor skills” necessary for success in the 21st century may dramatically change, despite those changes, one will need to be able to coordinate and adapt these skills. In fact, it is our ability to coordinate and adapt that will allow us to evolve with the world’s technological advancements.

In this paper, a new way of thinking about motricity was presented. It posits:

1) perception and proprioception are critical feedback mechanisms for psychomotor development,

2) psychomotor skills cannot be accurately categorized as fine or gross but rather should be defined based on measurable attributes, and

3) singular psychomotor skills have a linear progression from unconscious incompetence to unconscious competence, that is independent of their combination with additional skills or transfer to new situations, which can also have their own developmental progressions.
In using these three guiding principles to review diverse bodies of literature on motricity, two essential psychomotor skills that transcend fields emerged—coordination and adaptation. These are referred to as “meta-motor” abilities because they can be applied to any psychomotor skill, transcending typical subject- and/or occupation-bound categorizations.

Although psychomotor skills are presented separately from cognitive skills and knowledge, research suggests a link between motor development and cognitive development in children experiencing linguistic delays, even suggesting that motor development is a “prerequisite for cognitive development and academic learning”\textsuperscript{34,35} While overall there is weak evidence of correlation between motor and cognitive skills, results do suggest potential for interventions to stimulate high order cognitive along with motor skills.\textsuperscript{36} In fact, a recent study out of Germany found that “fostering the children’s physical fitness during the primary school age could enhance both motor and cognitive learning abilities related to the academic achievement.”\textsuperscript{37} Coupled with the rise in instructional strategies such as experiential and inquiry-based learning which often incorporate hands-on and other sensory approaches, it is easy to imagine reaping the benefits of combining psychomotor and cognitive skill development.

## Appendix: Major Psychomotor Taxonomies

The following table shows three main syntheses of psychomotor skills to date, and the way they fit into the analysis of this paper.

### Dave (1975)

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>CCR Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naturalization</td>
<td>Mastery/second nature</td>
<td>Unconscious Competence</td>
</tr>
<tr>
<td>Articulation</td>
<td>Coordinate + adapt a series harmoniously</td>
<td>Meta-Motor</td>
</tr>
<tr>
<td>Precision</td>
<td>More refined/exact</td>
<td>Measure</td>
</tr>
<tr>
<td>Manipulation</td>
<td>Perform based on memory or instructions</td>
<td>Trial and Error: Unconscious Incompetence, Conscious Incompetence, or Conscious Competence</td>
</tr>
<tr>
<td>Imitation</td>
<td>Observe + replicate with variable quality</td>
<td></td>
</tr>
</tbody>
</table>

### Simpson (1972)

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>CCR Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origination</td>
<td>Create new pattern for specific situation</td>
<td></td>
</tr>
<tr>
<td>Adaptation</td>
<td>Well-developed; can modify for specific requirements</td>
<td>Meta-Motor</td>
</tr>
<tr>
<td>Complex Overt Response</td>
<td>Skillful, complex, coordinated movement</td>
<td></td>
</tr>
<tr>
<td>Mechanism</td>
<td>Habitual, confidence, basic proficiency</td>
<td>Conscious Competence</td>
</tr>
<tr>
<td>Guided response</td>
<td>Imitation, practice, trial/error</td>
<td>Conscious Incompetence</td>
</tr>
<tr>
<td>Set</td>
<td>&quot;Readiness to act&quot; - mentally, physically, and emotionally</td>
<td>Prerequisite</td>
</tr>
<tr>
<td>Perception</td>
<td>&quot;Use sensory cues to guide motor activity&quot;</td>
<td>Prerequisite and ongoing feedback mechanism</td>
</tr>
</tbody>
</table>

### Harrow (1972)

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>CCR Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-discursive communication</td>
<td>&quot;effective body language, such as gestures and facial expressions&quot;</td>
<td>Specific subset of motor skills</td>
</tr>
<tr>
<td>Skilled Movements</td>
<td>Advanced movements including adaptation and integration</td>
<td>Meta-Motor</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Physical Activities</td>
<td>Stamina, fitness</td>
<td>Measure</td>
</tr>
<tr>
<td>Perceptual</td>
<td>&quot;Response to stimuli&quot;</td>
<td>Prerequisite and ongoing feedback mechanism</td>
</tr>
<tr>
<td>Basic Fundamental Movement</td>
<td>Simple tasks (e.g., walking)</td>
<td>Unconscious Competence (for tasks considered simple)</td>
</tr>
<tr>
<td>Reflex Movements</td>
<td>Automatic/not learned/involuntary</td>
<td>N/A</td>
</tr>
</tbody>
</table>
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