Exploring the notion 'cultural affordance' with regard to mathematics software

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About 10 years ago the Gibsons' notion of 'affordance' was extended to cultural objectives underlying designed computer systems. Chiappini (2012) extends this idea to mathematics software. We critically, but respectfully, review these extensions – does 'cultural affordance' add anything new to valuations of software for doing mathematics?

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Introduction

This paper is an exploration of the construct 'cultural affordance' (CA), and whether it adds anything to what we might, as mathematics educators, call 'rich software (SW) environments'. In the opening sections the first author outlines the genesis and development of the construct 'affordance', culminating in a recent extension applied to evaluating a SW system designed for learning/doing algebra. Then each author critically considers these developments of the construct 'affordance'. The paper ends with an overview and matters/questions for further consideration.

The development of the construct 'affordance'

E and J Gibson developed the constructs 'affordances', 'constraints' and 'attunements' over three decades, from the 1950s. A succinct account is:

> The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill … It implies the complementarity of the animal and the environment. … If a terrestrial surface is nearly horizontal … nearly flat … and sufficiently extended (relative to the size of the animal) and if its substance is rigid (relative to the weight of the animal), then the surface *affords support*. (Gibson 1979, 127)

Note that the Gibsons' affordances are very *basic* things – knives have edges that afford slicing. Norman (1988) equates affordances with perceived affordances, which is not the Gibsons' view – their affordances exist whether we perceive them or not. Norman (1999) corrects his earlier 'mistake' and rants on about the misuse of the term:

> it is wrong to claim that the design of a graphical object on a screen "affords clicking." Sure, you can click on the object but you can click anywhere. Yes, the object provides a target and it helps the user to know where to click and maybe even what to expect in return, but those aren't affordances, those are conventions and feedback (ibid, 40)

The construct is widely used in mathematics education; Watson (2007), for example, examines tasks and questions that afford participation in mathematics classrooms. This, to us, is a legitimate application of the construct – it considers what the environment (equipped with social norms) provides the animal (student) with appropriate attunements.

Turner & Turner (2002) take the construct much further, to what they call 'ergonomic affordances' and 'cultural affordances' which they introduce as:

> affordances for embodied action are peculiarly central to effective interaction with people and objects in a technologically mediated environment. In the real world, embodied action recognises the constraints of our physical bodies … embodiment allows us to use a wealth of non-verbal mechanisms and to make assumptions about the perceptual resources and scope for action of other embodied beings (93)
>
> A cultural affordance (CA) is a feature or set of features which arises from the making, using or modifying of the artefact and in doing so endowing it with the values of culture from which it arises. Unlike simple affordances or those which arise from embodiment, CAs can only be recognised (in an extreme sense) by a member of the culture which created it. CAs are exploited with the artefact in use and will change if the artefact is put to a different use. (94)

It should be noted that the Turners are not mathematics educators. They design and evaluate collaborative virtual environments (CVE). The project behind the theory they develop is important in terms of critical safety-training simulations in maritime and offshore work practices. Ergonomic cultural affordances may be important in safety-training SW, but does this importance extend to the culture of mathematics?

Giampaolo Chiappini is a mathematics educator and Chiappini (2012) applies the Turners' constructs to his software *Alnuset* designed for high school algebra. He starts by considering ergonomic affordances, e.g. the representation of algebraic variables on the line through sliding points associated to letters that can be dragged along the line with the mouse, and he lists a number of other ergonomic affordances. We agree that sliders in mathematics SW systems can provide an 'ergonomic affordance', because they afford interaction between the users' bodily movement and the system's graphical/symbolic representation.

Chiappini then turns his attention to CAs:

> The ergonomic affordances of … Alnuset are not sufficient in themselves to allow students to master the meaning, values and principles of the cultural domain which has inspired the creation of these ergonomic affordances … it is only through an activity that features which emerge from .. [Alnuset] … can be transformed into cultural affordances and can assume the values of the culture from which they arise. (138)

To address how these meanings and values may be acquired by students he turns to activity theory, focusing on "every human activity can be characterized by contradictions" (138). He adopts Engeström's notion of the *cycle of expansive learning* where the evolution of activity goes through a number of phases.

> The first phase … the assignment of an open problem on an important issue of algebra learning and concerning an obstacle of an epistemological nature. … Typically a conflict emerges in terms of an unexpected representative event as a reaction of the system software to the student action that appears surprising to their consciousness. …
>
> In the second phase … students are requested to face tasks that broaden problematic areas of the knowledge in question. … Tasks in this phase are designed in order to exploit the visuo-spatial and deictic ergonomic affordance of the algebraic line to allow students to explore the conditions, causes and explicative mechanisms of conflicts …
>
> In the third phase the use of the algebraic line is integrated with the axiomatic algebraic model incorporated into the AlNuSet algebraic manipulator…. In this phase the teacher encourages both the establishment of the algebraic axiomatic model in the student's practice and the development of meta-cognitive processes

> involved in the re-configuration in symbolic terms of the algebraic meanings expressed beforehand in visuo-spatial and deictic terms.
>
> In the fourth phase [the teacher fosters] … a full awareness by students of the developed knowledge through the comparison with the memory of their knowledge before the beginning of the cycle. (139)

John Monaghan's reaction

Chiappini's approach (and software, not described here – see his paper) is interesting, as is the evolution of the construct 'affordance'. Of the two constructs, 'ergonomic affordance' appears relatively unproblematic compared to 'cultural affordance'. But there is something appealing to the construct 'cultural affordance' with regard to the culture of mathematics and software used in mathematics learning and teaching. Spreadsheets are amongst the most widely 'mathematical' software in schools. Although they were designed for finance, not mathematics instruction, the quasi algebra, B2=2*A2+1, is 'cell arithmetic' and can only support the development of some cultural aspects of algebra. Spreadsheets afford 'filling down'. This ergonomic affordance can be appropriated by mathematics teachers to solve equations by a decimal search. For example, to solve $x^3=100$, we can fill down single digits in one column, fill down corresponding cubes in an adjacent column and see a solution between 4 and 5; we can then fill down between 4 and 5 in steps of 0.1 and see a solution between 4.6 and 4.7, etc. Such an appropriation is a cultural act on the part of the mathematics teacher (for one aspect of mathematics). It may be that the construct 'cultural affordance' permits us to hone in on affordances of software system that support (or do not support) aspects of mathematics that we wish to promote.

Chiappini brings in activity theory (AT) and Engeström's version of AT in particular – are these essential? Regarding AT, I think 'yes and no'. 'No', I'm sure that someone who is not particularly drawn to AT could put an interpretation on the transformation of ergonomic affordances into 'real' mathematical understandings by students which is not based on AT. 'Yes' in as much as AT does highlight that learning mathematics is a cultural process (would someone who is not drawn to AT even have an interest in the phrase 'CA'?) Now, with regard to Engeström's version of AT, I first note that there are a number of forms of AT. Engeström's version is a 'systems' approach and it could (and has) been argued (see LaCroix 2012) that it is too big to capture the nitty-gritty details of students' actions in doing and learning mathematics. Personally I suspect the AT approach of Luis Radford (see LaCroix, 2012, again, for details), who looks at nitty-gritty student details and pays close attention to gestures (which could be called ergonomic actions), may be a more suitable AT approach to looking at how the affordances of a mathematics SW system can assume, in the words of the Turners (above), "the values of the culture from which they arise".

Further to this, there appears to be a certain 'Italian flavour' to Chiappini's version of the Engeström approach. By this I mean, it is certainly an Engeström-based approach but I have detected that an Italian way of sequencing learning and teaching involves initially presenting students with tasks that are beyond their technical powers and then attending to technical matters in intermediate lessons before returning to a form of the original task; and this is basically what happens in the four phases above. Now there is much to laud in this approach to sequencing learning and teaching but there are other means as well. There is thus a sense in which Chiappini may be 'prescribing' rather than 'describing' students' actions; I do not see anything wrong in prescribing as long as we realise that what students do may differ to what we want them to do.

Finally it needs to be asked whether the construct 'affordance' has been stretched too far from "affordances are very *basic* things, knives have edges that afford slicing"? To "assume the values of the culture from which they arise" requires an elaborate peopled environment with specific tasks and sub-tasks "designed in order to exploit the visuo-spatial and deictic ergonomic affordance" of a specific artifact (Alnuset). Now I do not see anything 'wrong' with this elaboration, I just wonder whether the Gibsons would recognize the animal-environment relation in this account.

John Mason's responses

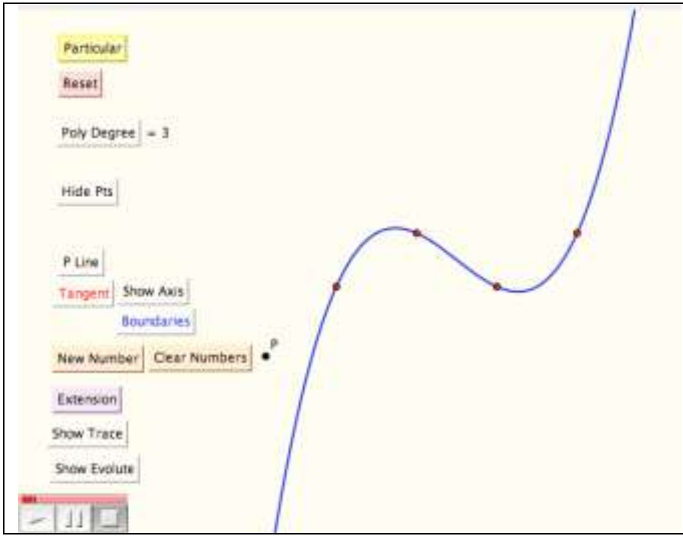
The notion of 'cultural affordances' has an immediate appeal for me, at least until it runs up against the Gibsons' insistence that they be independent of people, time and place. It seems reasonable, even indisputable that immersion in a culture provides access to cultural tools, whose attunements then afford specific actions. For example, recognizing the possibility of studying a set of objects by studying actions acting on those objects (in the way that, for example, analysis studies the reals, rationals and complex numbers by studying various families of functions, or Klein's approach to geometry as the study of groups of permissible actions).

It seems to me that the CA construct with respect to software is a portmanteau for the enculturation of one or more people into (some aspects of) a culture enjoyed by the author of the software. It is the finer grained analysis of that enculturation which is of interest to me, and I suspect to most mathematics educators.

I find the notions of *affordances*, *constraints* and *attunements* powerful triggers to direct attention to important aspects of tasks generally, and software in particular, but only by seeing them as evolving and developing during activity. Affordances perceived at the beginning are usually a subset of the affordances recognized later. Trying to encompass all of the affordances as basic, absolute affordances fails to take into account the user and their evolving attunements. For example, in spreadsheets, 'fill down' offers both ergonomic and cultural affordance. Treating affordances as the union of all possible basic affordances in all possible situations takes away the power of the framework for identifying what is possible in-the-moment, moment-by-moment.

One approach to a finer grained analysis of enculturation into, exploitation and evolution of affordances could be through *activity theory* as used by Engstrom or Radford. Another could be through abstraction of Bruner's trio of modes of (re)presentation *Enactive–Iconic–Symbolic*.

Take for example one of my own applets: *Tangent Power* (Mason 2012). Define the *tangent power* of a point P with respect to a function *f* to be the number of tangents through *P* to the graph of *f*. Some initial questions might be: What tangent powers are possible and where are the points with a given tangent power? What are the greatest and the least possible tangent powers, and where would these points they be found? These are outer tasks (Tahta 1988) to initiate activity. An inner task (not to be made explicit until after work on the task) is encountering inflection points as the places where the first derivative changes direction.



I usually start with a quintic, displayed by pressing the Particular Button at the top left hand side of the screen.

At first sight there are a mass of buttons and a prominent graph.

What the buttons do will only emerge through trial or through watching someone drive the software.

Following Turner & Turner and Chiappini

Usability (affordances): Fine-motor coordination required; reasonable eyesight; focusing on some parts of the screen while ignoring others.

Ergonomic affordances: There appear to be buttons that could be pressed, but even recognizing these requires some cultural capital; you can drag a point along an axis which drives a tangent to the curve; you can display boundary regions; you can create a point with a number-label to use as a label for the tangent-power of a region.

(Local) Cultural Affordances: Unless you have been told or shown, it is not evident that to change a number (such as Poly Degree or New Number) you click-and-hold while typing in an appropriate number.

(Global) Cultural Affordances: Opportunity to explore various particular instances of a phenomenon, and to generalise to a broad class of functions; opportunity to challenge your sense of what happens to tangents at points with large (in absolute value) *x*-coordinate; opportunity to challenge assumptions (concept images) about tangents and whether they can cut or be tangent to a curve 'elsewhere', or even cross the curve at a point of tangency; encounter geometric implications of a first derivative having an extremal value.

Constraints: Polynomials of degree up to 7 whose variation fits on the screen.

Attunements: Users need to have some familiarity with graphs of functions and tangents; in order to concentrate on the mathematical relationships and properties, it is necessary to develop some facility with the use of the buttons etc.

Following Bruner

Enactive Affordances: Dragging (and animating) a point to animate a line through a point or a tangent to the curve; dragging red points alters the curve; extension permits a line at a fixed angle to the tangent; display of curve enveloped by those lines.

Iconic Affordances: Stabilising the image of particular polynomial, with a (possible) sense of generality through the possibility of dragging red points to change the polynomial; stabilising a particular position for point P and a particular line through P; allowing line through P to be varied; stabilising image of a tangent; animating the tangent; providing instances of enveloped curve when lines are at a fixed angle to the tangent, for making conjectures.

Symbolic Affordances: Not really present;

Overview

Seeing CAs as 'features arising from making, using and modifying artefacts' draws attention to how conditions make some things more likely, and other things unlikely or even impossible, so that both affordances and constraints contribute to creative potential. Moreover, the affordance expected may not be the affordance experienced.

Seeing CAs as 'internalised', 'condensed', 'reified', 'semantic contractions' offers a psychological contribution, because what I make of and do with an artefact can be slightly different to what you make of and do with it. For example many people do not seem to make use of the affordance of styles in MSWord, yet it is present, but perhaps not perceived, or if perceived, not acted upon for various idiosyncratic as well as social reasons. Each user of a cultural artefact brings to it their own propensities, stressings and ignorings, and intentions, so the artefact itself, as an object in the material world may look the same, yet in conjunction with a person in a social setting may bring to mind different possibilities.

Might not the adjective 'cultural' mislead attention away from the personal, the psyche of the individual (their awareness, enactive potential and affective states) as an important component? The cultural and indeed the historical play a role in the genesis, but the condensation-contraction is likely to be personal. If the person's state were dominantly social, wouldn't everyone in the class give the same response to a teacher's probe, or at least the group would agree on a response?

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