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Entry

Educational Constructivism

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Definition: A perspective on learning and teaching that considers knowledge must be constructed by the individual learner using available interpretive resources, and where learners are likely to misconstrue instruction without well-designed teaching that is informed by knowledge of learners' ideas.

Keywords: constructivism; constructionism; teaching; learning; alternative conceptions; misconceptions; pedagogy; interpreting texts; knowledge; curriculum

1. Introduction

The term 'constructivism' is used with some variation in meaning in a range of fields, including philosophy and the scholarship of research methods in the humanities and social sciences [1,2]. While the different uses are not unrelated, the present article is concerned with the notion of constructivism as understood in the field of education, in relation to the study of learners' developing thinking, and the labelling of some approaches to teaching as 'constructivist'. This educational constructivism is sometimes known by alternative terms, such as pedagogic constructivism, or psychological or cognitive constructivism. The related term, constructionism, is also used in different ways but, as explained below, 'social constructionism' usually refers to a somewhat distinct set of ideas.

These various versions of constructivism all concern themselves with, and problematise, how people come to knowledge, and the philosophical (metaphysical) accounts are inconsistent with any naive realism about natural science (that is that scientific accounts can be known to strongly reflect an actual independent, objective reality). So-called 'radical constructivism', which takes an epistemological stance that we can never know that our conceptions of the world do truly reflect an objective reality [3], has been influential in education. However, as explained below, educational constructivism is primarily concerned with learning about knowledge set out in some form of curriculum, but without regard to the absolute status of that knowledge (e.g., objective truth or culturally contingent human construction). As one commentator noted, this makes the claims of metaphysical constructivism 'almost entirely irrelevant' to education [4].

The terms constructivism and constructivist are commonly used in discourse around teaching and learning, but have been especially common—sometimes perhaps dominant—in relation to science and mathematics education [5–7]. Constructivist ideas are also increasingly influential across the curriculum and in all phases of education [8–11]. There is also some diversity in how 'constructivism' has been evaluated. While constructivism has become almost a by-word for modern teaching methods in many countries and has informed formal documentation in national teaching policies [12–16], it has also been seen by some commentators, especially in the United States [17], as indicating an approach to teaching that is motivated ideologically and that falls short of other educational approaches (and, in particular, is inferior to what is labelled as 'direct instruction').

Given that, similar to most social concepts, constructivism is to some degree differently understood by different scholars [18], it is important to acknowledge at the outset that this entry takes a position. That position is that educational constructivism, in the sense in which the term is set out here, refers to a perspective on teaching and learning that is highly influential in both research and the practice of teaching, and that is supported by

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key findings from basic research into human learning. It has also been demonstrated to be effective in myriad studies on teaching and learning in fields such as science education, although it should be acknowledged that most of these studies suffer from severe limitations, including the challenges of attempting experimental research in the context of classrooms, where control of variables is seldom perfect [19].

2. The Relationship with Social Constructionist Positions

Educational constructivism shares some, but not all, of the principles commonly associated with social constructionism. It is, therefore, useful to briefly describe this broader position, before explaining which aspects are seen as essential to educational constructivism. Social constructionism is the position, supported by a range of scholarship in the humanities and social sciences, arguing the view that experienced reality is socially constructed [20,21]. So, for example, ideas about what is meant by a clinic or hospital or mental illness are historically and culturally relative [22]. To take an example from education, there is no neutral ontological account of schools. Schools do not exist in the natural world outside of human activity, and what counts as a school is decided by human discourse and is subject to change over time. Indeed, people can justifiably disagree on whether a particular potential exemplar (say a dozen children being taught in a family home by a rota of the parents) counts as a school. There may be a definition set out in a legal or other institutional framework, but this is a contingent outcome of political, ultimately discourse, processes, and so is open to being changed in the future through similar processes. As another example, a learner who is evaluated as 'gifted' in a particular cultural context may no longer be considered gifted if transferred to a different national (or even district) system. What counts as giftedness is socially constructed.

Moreover, multiple discourses may be recognised, through which different accounts of reality may be constructed. What counts as a gifted learner may be quite different in different cultural, institutional, or curriculum contexts. From such a social constructionist perspective, there is no sense in asking whether, say, someone falling ill is 'really' due to (a) infection by a disease microorganism or (b) an imbalance in the humours or (c) a neighbour engaging in witchcraft, as these are seen as constructions from within different discourses with equal validity. The argument being that there is no neutral and so completely objective standpoint (that is, no 'God's eye view') from which fair comparative evaluations could be made.

Educational constructivism can be understood as a partially independent set of ideas, with a focus on epistemology rather than the nature of reality. Educational constructivism is primarily concerned with how individuals come to form knowledge and understanding of the world, and especially in relation to target knowledge set out in the curriculum. So, for example, the school science curriculum might set out particular accounts of, inter alia, the human circulatory system, chemical elements, and quasars. Now bodies, elements, and stars are entities found in nature that, it is assumed (at least by natural scientists), exist without reference to human action in the world, and are not culturally contingent. There are certainly arguments about epistemological questions—how well can we know nature, how can we be sure our knowledge is valid?—and it is now widely recognised both that (i) science offers provisional, fallible knowledge of the world [23] and that (ii) the construction of scientific knowledge can be influenced, even biased, by cultural factors and human values [24]. As an example, the widespread acceptance of the heliocentric (as we now frame it) model of our solar system was clearly impeded by common assumptions deriving from religious teachings. There is a spectrum of views on the extent to which such extra-scientific factors have framed our scientific accounts, but most scientists themselves assume science is incrementally approaching accounts of the natural world that better reflect a reality that exists independently of humans or our conceptions of it.

There is also an interesting area of scholarship that considers how scientific accounts are necessarily distorted in the processes of being represented in the curriculum as target knowledge and of teaching [25]. The primary scientific literature is constantly being updated and contains many claims that are no longer accepted, as well as claims that are still seen as speculative and claims that are currently widely accepted in the relevant fields. So, there is no undisputed, authoritative source for the current scientific account of some given topic that a teacher or student could refer to. Review articles and handbooks offer something approaching an authoritative view of a topic, but these are only updated or supplanted from time to time, and still reflect the views of particular authors. They are also written at a technical level for peers, other experts, so textbooks are prepared that present accounts (selections and simplifications) more suited for learners. Curriculum design also involves selection and simplification of the technical accounts [26], and whilst these interpretations will be pedagogical (to suit a student cohort), they are open to other biases, such as politically or ideologically influenced views about the relative merits of different potential content items—hence the involvement of U.S. courts in questions such as whether natural selection and/or intelligent design should be taught in school science classes.

However, educational constructionism largely puts aside these questions of how well curriculum accounts match nature (or, in the social sciences, how well curriculum accounts match the positions of particular scholars), and usually tends to take this target knowledge as a given reference point and then enquires into:

- what learners think in relation to curriculum topics, and how this relates to the curriculum account,
- how learners' thinking changes, and, in particular, is influenced by teaching,
- how teachers can best support the process of shifting student thinking towards the target knowledge set out as curriculum accounts.

Teachers interpret curriculum specifications in planning their teaching. This also admits potential for distortions that are made due to personal bias (e.g., deciding to limit coverage of a topic considered as not important or not especially interesting), as well as judgements made about (further) simplifications needed to make material accessible to particular learners. It is also possible for teachers themselves to misunderstand the material they are asked to teach [27]. All humans, including teachers, learn through the same basic cognitive processes, and teachers are subject to the same issues and challenges in their learning as others. So, teachers may themselves hold alternative conceptions, and some studies have explored and demonstrated this.

Some social constructivist positions see language as not simply a medium for expressing pre-existing ideas, but as the source from which such ideas derive. Moreover, such positions often reject notions of the discrete individual having inherent psychological qualities and mental states, rather seeing social interaction through dialogue as the source of our ideas and (dynamic) personalities [28]. By contrast, while the personal educational constructivist position described here acknowledges the importance of culture and social interaction in shaping the development of the individual, and the central role of dialogue in teaching and learning, it accepts the meaningfulness of, and considers it perfectly appropriate to focus on, the cognition and mental states and resources of individuals. From a methodological perspective, it is important to appreciate that research reports of learners' ideas usually reflect data constructed in a specific social context—a student responding to an examination script, a group of learners discussing a task in class, or an interview with a researcher—and such data are, therefore, always somewhat co-constructed; however, the educational constructivist considers that such data can still offer insights into the pre-existing knowledge and understanding of the individual learner.

Social constructionist perspectives often adopt a post-structuralist stance on texts, such that there is no default or privileged meaning in a text—so that each person's interpretation (including that of the text's author) is equally valid [21]. The constructivist position discussed here shares the view that a text has no inherent meaning (as it is a representation of meaning, not meaning itself) and so must be interpreted, but *does* privilege the teacher's intended meaning (as 'target' understanding), as the educational process is largely evaluated (as reflected in formal school examinations) in terms of learners interpreting texts as intended. The fact that a text such as a teacher's explanation or a textbook chapter does not have the affordance of automatically sharing meaning is, therefore, recognised, but it is also seen as being problematic in a teaching context. Indeed, educational constructivism can be seen as a response to the impossibility of 'transferring' (i.e., copying) knowledge and understanding directly from the teacher's mind to the minds of learners.

3. Social or Personal Constructivism?

The constructivist perspective that has been widely adopted in educational contexts is a form of a personal constructivist position, as it acknowledges the individual as the focus of knowledge and understanding (in contrast to the social constructionist perspectives discussed above) and sees learning as due to cognitive processes taking place in, and leading to changes in, the individual learner. However, formal education involves learning about products of the culture, which has a socio-historical development [29], and which requires the mediation of someone already encultured (the teacher) through the symbolic tools of the culture (such as language). Moreover, learning is seen as heavily dependent upon dialogue and opportunities to talk through and about new ideas, so they are understood and reinforced [30]. Educational constructivism, therefore, recognises the critical role of the social context and processes of the classroom, while retaining the notions of individuals as valid discrete epistemic ('knowing') subjects. Different accounts and commentators put different emphases on the relative importance of the individual and the group. Despite the difference in focus between personal constructivist accounts and social constructivist (sociocultural) accounts of learning [31], these approaches may be consistent [32], and indeed a full account of classroom learning needs to include both aspects.

Though substantially oversimplifying these ideas, the following list may help differentiate the distinct use of several related terms:

- **Social constructionism** suggests (social) realities are constructed through social processes, such as discourse and human institutions, and often considers the locus of knowledge to be the group/community.
- **Educational constructivism** suggests that learning (e.g., of abstract conceptual principles) is a process contingent on the limitations of human cognition, and channelled by existing thinking, and that teaching that will be effective when responding to these factors.
- **Personal constructivism** (within education) is a perspective that largely focuses on the role of each learner as an individual epistemic subject with an idiosyncratic repertoire of knowledge, and the learner's cognition during learning.
- **Social constructivism** (within education) is a perspective that largely focuses on the role of social contexts and interactions, especially through dialogue, in supporting learning.
- **Constructionism** (within education) is a perspective that sees the core loci for learning as group activities that are directed towards the development of some form of authentic product.

4. Origins of Educational Constructivism

In retrospect, it is possible to recognise aspects of constructivist strategies in the teachings of historical figures, such as Jesus and Socrates. However, the adoption of 'constructivism' and 'constructivist teaching' into mainstream educational discourse has its origins in the first half of the twentieth century in a variety of thinkers about child development and education. It also relates to the nineteenth century notion of the 'heuristic method' in teaching, which sought to put learners in the role of making discoveries through engagement in enquiry activities [33].

The pragmatic philosopher and educationalist, John Dewey, emphasised the importance of practical activity in learning, recognising the poverty of teaching that was simply passing on information [34]. For Dewey, conceptual learning was experiential and involved reflection on actual engagement with a practical problem [35]. Jean Piaget [36] studied the cognitive development of learners and posited that the young child grows mentally into an adult through a series of stages in which new mental abilities appear and, moreover, that there is a sense that the acquisition and application of the new abilities in one stage provides the foundation that allows further development. In particular, the ability to operate on abstract mental representations only appears during adolescence. This is highly relevant for learning in mathematics and science given that these subjects require just this kind of thinking [37]. Examples might be such concepts as the ideal gas law, the principle of conservation of energy, Mendelian inheritance, or deviations from Raoult's law. In such cases, learners are asked to operate on representations of relationships between abstract ideas (as the learners can have never seen, for example, energy or directly handled genes).

Later work by William Perry [38] suggested that acquiring this level of (what was called) formal operations did not represent an end-point for intellectual development, as it was not sufficient to equip learners to cope with situations where they were asked to solve problems in the face of incomplete and messy scenarios (as in many real-life problems) or in situations where decision-making cannot rely upon *just* the logical analysis of factual data. Increasingly, such demands are made of school children; thus, in many countries, it is now considered important for learners to study socio-scientific issues [39]. As one example, in addressing the question of what level of species extinction would be acceptable in order to maintain current levels of economic development, there is much complex information available from a number of fields that can inform the issue. However, no database would be sufficient in reaching a conclusion, as the question also has a moral dimension. Science and other fields can guide learners on the levels of extinction likely to be caused by different levels of economic activity (deforestation, mining, industrial fishing, etc.) and how these different levels might impact on such matters as gross domestic products and mean income levels. Science can also offer guidance on the potential values of the resources that biodiversity offers (for example, in developing new medicines). However, decisions about how many slightly different species of butterflies or fish or birds it is acceptable to lose will depend on personal systems of values.

Piaget's contemporary, Lev Vygotsky, also studied human development but as part of a broader perspective that also considered human evolution and cultural development more generally. Vygotsky had a strong focus on how culture is communicated through human societies [29] and the key role of language and other forms of mediation in this [40]. He recognised how development (in the sense of learning that goes beyond just adding new details to existing knowledge and skills) allows a person who has no competency in some area to move to some degree of mastery only because of the role of others who could provide 'scaffolding' during the learning process. This scaffolding [41] involved a shift ('fading'), such that the initiate begins as little more than an onlooker but slowly takes over the activity being modelled for them as competence (and confidence) grows.

Vygotsky suggested that a learner's development takes place in what is referred to as the zone of proximal (or next) development, often simply referred to as the ZPD. In effect, Vygotsky suggested a model in the form of a kind of multi-dimensional phase-space, where the dimensions relate to different potential human capabilities. This space was considered to have three general regions: a zone of actual development, ZAD, where an individual had already achieved mastery; a zone of distal development, ZDD, where competence was well beyond the learner's current capabilities; then, between these, a kind of buffer zone, where activities were only somewhat beyond current capabilities, the ZPD.

Activity set in the ZAD can provide 'drill and practice', where a learner may become faster at a task and come to less often make errors but this does not lead to the development of new capabilities. A task set in the ZDD would frustrate a learner who could not make any progress with it. If the learner was part of a group, then she might be able to assist other more advanced learners when following their instructions but would not be able to substantially learn from the experience. However, within the ZPD, the learner who works with a more advanced person or persons can learn from the activity if provided with suitable 'scaffolding'—modelling, advice, guidance, and hints. Initially, this might amount to being completely dependent on being shown and told what to do, but the learner will come to internalise the activity and so the scaffolding can be 'faded' as less support is needed, until the learner no longer requires any help (at this point, the learner's ZAD will have expanded to encompass a newly mastered competence). The ZPD is unique to a particular learner, so not all learners who have the same current capacity for, say, composing music, will have the same potential for 'next development'. (We might suggest the ZPD is 'narrower' for one learner than another, so they are ready for different degrees of challenge in their learning). Based on this model, Vygotsky strongly recommended the educational importance of not simply knowing what a learner could currently do unaided, but what she is ready to start to tackle with suitable support; that is, identifying a learner's ZPD.

Vygotsky was primarily, if not exclusively, concerned with development, but studies of skills learning in various social contexts (learning a trade or acquiring a skill within a group context) have been found to reflect this finding [42]. Vygotsky recognised the role of symbolic representation in communicating culture, including but not limited to natural language. School learning in subjects such as science and mathematics introduces young people to a wide range of such representational systems (periodic tables, Cartesian graphs, chemical symbols, calculus, food webs, etc.).

Both Piaget and Vygotsky recognised that the initial learning of the young child was based on direct experiences. Piaget's background was in biology, and he saw young children as organisms acting on their environment and learning from the feedback received—what they experienced when they clutched, grabbed, sucked, dropped, etc. The human brain would abstract from individual experiences to construct expectations about the outcomes of future interactions. Thus, concepts are formed, though these are not yet explicit (open to introspection), and in the pre-verbal child they could not be expressed through language. However, Vygotsky recognised that it was such spontaneous concepts that provided the most basic resources for constructing more abstract ideas.

The construction of knowledge is an iterative process, and no matter how abstract the learning, it is built (if sometimes very indirectly) on direct experience of the world. The American psychologist and educational theorist, Jerome Bruner [43], provocatively suggested that any subject matter could be taught to a child of any age in an intellectually honest manner—that is, through a simplification that retained the essence of the canonical idea. Vygotsky (working in the Marxist regime of the Soviet Union) understood that conceptual development involved a dialectical process whereby the formal taught concepts could only be made sense of in terms of the background of spontaneously developed concepts—but, also where these taught concepts provided the means to reflect upon and discuss the spontaneous concepts. Vygotsky recognised that the learner's conceptions were organised into some kind of system rather than being a set of discrete isolated features of cognition. A somewhat similar perspective was offered by George Kelly's [44] personal construct system, which saw each individual as understanding the world through developing a unique set of personal bipolar constructs that were organised into a system. These constructs were, in principle, open to being modified, to allow the individual to see the world in a new way, but some constructs would be more resistant to change than others.

Vygotsky thought that language arose originally to allow communication in the small social groups in which early humans lived, foraged, and hunted. However, once people had language in which they could talk to others, they were able to adopt this new tool for another purpose—private speech—a symbolic system that supported deliberation, planning, problem-solving, and so forth. Similar ideas were developed by George Herbert Mead [45], the originator of the symbolic interactionist perspective. In his description of the relationship between spontaneous and taught (so, symbolically represented) concepts, Vygotsky did not think that each of these two different types remained distinct while just providing resources for the other, but rather that interaction (through 'moving together') enabled the formation of concepts that were actually hybrids—melded concepts—with roots both in direct experience and abstract representation.

The educational psychologist, David Ausubel [46], emphasised a distinction between two types of learning: rote and meaningful. Rote learning is just memorising without any understanding (being asked to learn a phrase in a completely unfamiliar language may come close to this). Meaningful learning involves the learner making sense of new information in terms of prior knowledge, experience, and understanding. It is quite possible for there to be no meaningful learning even if a learner has relevant prerequisite knowledge if its pertinence is not spotted. For that matter, meaningful learning need not be canonical. A learner may understand new material in terms of pre-existing alternative conceptions (misconceptions) of the topic, or indeed may associate it with prior learning, which from a canonical perspective is unrelated and not pertinent. Ausubel [47] famously suggested that the most useful advice for teachers is to find out what learners already thought, and to teach accordingly. This has strongly influenced educational constructivism. Indeed, Ausubel's dictum, "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly", can be found widely quoted on websites for examinations boards, individual schools, teacher's networks, educational blogs, subject teaching associations, school improvement organisations, and the like (web-search undertaken with Google search engine, 31 September 2024), as well as in scholarly literature.

5. The Alternative Conceptions Movement and Learners' Science

From the late 1970s, there was an extensive research programme, in science education in particular, to find out just what learners did think [48]. This has been labelled as the alternative conceptions movement. Decades earlier, Piaget [49] had reported that even young children, rather than just being ignorant prior to schooling, offered a vast array of alternative notions about the world when asked about, say, why winds blow or why the sun cannot be seen at night. Researchers asked school children of different ages, and from various countries, what they thought about force and motion, heating, the structure of matter, light, the heart, chemical reactions, and so on. What was discovered was that very commonly, learners came to class with existing ideas about the topics they were to study that were inconsistent with the target knowledge to be presented to them [50,51]. At least some of these misconceptions, or alternative conceptions (or preconceptions or intuitive theories—various terms have been used), were resistant to change and either survived teaching intact or distorted teaching so that what was learned did not match what the teacher sought to teach. Given the ever-expanding list of reported alternative conceptions, critics rightly suggested that not every alternative idea offered by a learner would present a major challenge to teachers [52]. However, many clearly did, and there was even some evidence of alternative conceptions surviving schooling, degree courses, and admission into teaching roles [53].

An extensive and somewhat inconsistent literature developed, but some common principles could be recognised in some of the most influential work in science education [54–58]. So, the following hard core of a constructivist programme has been identified [59]:

- Learning science is an active process of constructing personal knowledge.
- Learners come to science learning with existing ideas about many natural phenomena.
- The learner's existing ideas have consequences for the learning of science.
- It is possible to teach science more effectively if account is taken of the learner's existing ideas.
- Knowledge is represented in the brain as a conceptual structure.
- Learners' conceptual structures exhibit both commonalities and idiosyncratic features.
- It is possible to meaningfully model learners' conceptual structures.

Clearly, much of this also applies to other curriculum areas.

Some of the scholarship in the field was informed by considering cognition through an information-processing model [60]. A particularly important feature was work on working memory, which showed that people have a very limited capacity to keep in mind multiple items of information [61,62]. However, it was also found that what counted as one item in this regard was not fixed. The notion of 'chunks' was mooted: unfamiliar material arriving in working memory from the senses would be 'processed' as minimal items of information, but more complex material represented in an integrated form in long-term memory could be accessed and 'processed' as much more extensive chunks [63]. This results in an inherent bias in human cognition for the familiar over the unfamiliar [64]. Other relevant research into memory suggested that integration of new material into long-term memory was not automatic, and was supported by reviewing learning, and that the nature of memory was reconstructive [65]; that is, memory is not a store in which items are placed and can later be retrieved unchanged, but rather that material is *represented* in memory and those representations can allow the reconstruction of something similar to the original material (so less like something handed in at a lost property office, and rather more like a police report of a missing item). However, sometimes reconstruction relies on a 'filling in' of gaps in material with what seems feasible—so what is recalled may be distorted. It was also found that each activation of a memory could change it. Moreover, the notion of memory as a discrete faculty that can be called upon under deliberate control was over-simplistic, as experiences modify the perceptual system such that the way we perceive the world changes—a kind of 'memory' that influences cognition prior to perceptions reaching conscious awareness.

There is an extensive literature theorising learning, and teaching, in terms of constructivist principles, some of which explicitly draws on psychological work in learning and cognition [66–69]. There is also an even more extensive literature reporting on alternative conceptions in various curriculum topics identified in studies with samples of different learner populations in terms of age/grade and national context [50,51,70–72].

6. Examples of Alternative Conceptions

Researchers have reported alternative conceptions across a wide range of curriculum topics in science, where much of the research attention has been focussed. While less attention has been paid to concepts from some other curriculum areas, it seems likely that alternative conceptions will be widespread for all 'taught' concepts that are acquired through the culture (including formal education, but also the family, the media, etc.), as these rely on the same social and cognitive processes. The research in this area is extensive, and here just a few illustrative examples will be discussed.

One of the most explored areas concerns conceptions of force and motion [73–78]. It has been found that most people find Newton's laws of motion counterintuitive, and in particular hold the alternative conceptions that:

1. a moving object will spontaneously come to a stop without the action of any force,
2. a moving object is subject to a force acting on it in the direction of travel.

So, for example, when an object is thrown up in the air, it may be suggested that it in some way retains the upward force from the hand, which becomes 'used up' by the highest point, at which point gravity starts to act to bring the object back to earth. Although there are variations between individuals, it has been argued that something around four-fifths of people present with variations on these ideas. 'People', rather than learners, as it has been found that often, these alternative conceptions are retained despite teaching of the formal physics account. It has also been found that where successful students can apply the canonical physics in answering questions set in formal contexts, they may revert to their alternative conceptions in response to 'lifeworld' (everyday) contexts [79].

Another very common alternative conception found among learners is that chemical processes occur because atoms 'want' or 'need' octets of electrons or full outer shells [80]. This core notion can come to be the critical element in an extensive alternative conceptual framework used to explain chemical reactions, chemical reactivity and stability, bonding, patterns of atomic ionisation, and much more. Again, there is much variation in the precise details (e.g., ranges of application) in the ideas of different learners, but the basic misconception here seems to be extremely common in learners in many different national contexts [81]. In contrast to the example of alternative conceptions about force and motion (where common experience suggests that objects do seem to slow down and stop of their own accord if one is not aware of resistive forces acting), the development of an alternative conceptual framework focused on the electronic structures of individual atoms is clearly not *directly* based on everyday experience, and seems to be the outcome of learners' intuitions interacting with the models presented in teaching.

As an example from a biology topic, it has been found that learners may assume that green plants only (or mainly) respire at night when it is too dark for photosynthesis to occur [82]—seeing these two processes as two options for how plants can acquire energy. It has also been found that advanced learners with strong academic backgrounds, who can explain the nature of photosynthesis, and indeed provide the basic chemical equation showing how sugars are built up from water and carbon dioxide, will often respond to being asked where the carbon-based material came from to build up a tree by suggesting through the roots. (That is, again, the framing of a question may influence whether a canonical or alternative conception is elicited).

7. The Characteristics of Alternative Conceptions

The significance of learners' alternative conceptions has been questioned [52,83,84]. Early arguments that these were tenacious aspects of thinking with important consequences for teaching and learning were countered with the argument that learners' thinking was promiscuous and piece-meal, and elicited alternative conceptions were ephemeral and best ignored. This reflected an observation of Jean Piaget [49] that young children would often 'romance' responses to unanticipated questions. So, for example, if an interviewer asked where clouds come from, and the child had never considered this and had no ready response, the context (adult questioner and question) often encouraged the learner to suggest an answer in the moment—a thought provoked by the interview context that might otherwise never have occurred to the child.

The vast catalogue of work reporting, and sometimes characterising, learners' ideas, suggests that learner's conceptions actually vary across a range of dimensions [51]. The ideas elicited from learners can differ:

- In their match to curriculum accounts, so that alternative conceptions may approach target knowledge or be completely contrary to it.
- In their explicitness—some alternative conceptions are readily accessed as verbal accounts that the learner can reflect upon and is fully aware of, but people also have many tacit notions ('intuitions') that are not open to direct introspection, but which influence thinking. In such a case, a learner may respond to a question with a verbal explanation for some phenomena that is in itself novel and created in the moment, but that reflects a well-established underlying, but implicit, 'intuition'.
- In their embeddedness within thinking, that is, the extent to which they are integrated within networks of ideas. Some notions are, in effect, isolated ideas, but others may be supporting and supported within extensive conceptual frameworks (such as the example discussed above of atoms wanting to fill their electron shells).
- In their multiplicity—people sometimes have multiple alternative ways of thinking about or explaining phenomena, and switch between them depending on the example or context. The ranges of application learners demonstrate for alternative conceptions do not always coincide with that of the canonical accounts, so they may not appreciate these as alternatives but consider them as different principles that apply to different phenomena. However, sometimes learners recognise the alternatives as options to be selected from depending on examples (or even as complementary accounts). Other times, a learner may present with an alternative conception that is their only available way of making sense of a class of phenomena.
- In the level of commitment that the learner has to the idea. While learners may be very readily persuaded some alternative conceptions are in error, others may be strongly believed. Extreme cases may include ideas that a learner associates strongly with their cultural and community identity. As one example, some learners reject natural selection or macroevolution in general because they have a strong commitment to the independent, separate ('special') creation of different species (or some larger taxonomic

groupings), which they consider (sometimes incorrectly) to be an article of faith in their family religion.

As each alternative conception can vary along at least these five different dimensions, it is clear that both their significance for student learning, and thus the challenge for the teacher seeking to address them, will also vary considerably. Not all alternative conceptions will be major impediments to the learning of curriculum target knowledge. Some will be readily replaced or modified by teaching without special attention. However, some will block or distort teaching, and those cases will undermine teaching unless explicitly addressed.

8. Constructivism and the Transfer Model of Teaching

The constructivist account of learning may be contrasted with the perspective that it replaced. The earlier perspective may be considered a naive (or common-sense or folk) view of learning, sometimes described as a 'transfer' model—though better understood as a copying model [85]. Here, learners begin as if empty vessels to be filled with knowledge, or as tabula rasa—blank slates—on which knowledge may be inscribed. The teacher brings knowledge that by careful presentation is often said to be 'transferred' but is better understood as copied into learner's minds. This folk model treats knowledge as something that exists in the material world—similar to water, perhaps—and that with sufficient skill can be moved around and poured into learners' minds. When presented in this way, such a model may seem obviously naive to anyone who has worked in education, even though it has been described as the educator's previously "accepted model for instruction" [67]; however, like many lifeworld ideas, it is often largely held by lay people as a tacit assumption rather than an explicit notion that is open to reflection. A key problem with such a simplistic account is that when a teacher presents material to a student who does not learn it, then it would seem the explanation must either be that the teacher is not an effective teacher or—especially when others in a class have successfully learned the material—the student must be at fault: perhaps inattentive, lazy, or stupid.

The prevalence of computers and associated digital devices in the modern world often leads to an analogy being made between computers and brains. Such an analogy has some affordances and can be useful in some circumstances. Brains, similar to computers, process information, can access internal databases, are able to 'store' small amounts of data for processing, can represent large amounts of information in long-term memory, can interface with other devices (sic, brains), and can even be networked.

Files are readily copied from one computer to another—as, for example, when downloading a webpage from the internet or sending an email attachment. A file prepared on one computer can be copied to another as a perfect replica, such that text in a file will be displayed on the second computer in perfect fidelity. Those who know about computers will appreciate that when a file is copied from one computer to another, it does not pass through the link (a cable or a Wi-Fi or Bluetooth channel) as is, but gets coded into a signal that allows a precise replica of the original to be reconstituted from the signal. That is, a pdf file cannot move across the internet, but the precise instructions for rebuilding it can.

That none of this is a natural, automatic state of affairs will be recognised by anyone who has, for example, tried to open a (copy of a) file produced on an Apple Mac computer using Mac software, on a computer running a Microsoft operating system, or even someone trying to open an old file prepared using an earlier version of the 'same' software that was designed for a now defunct type of central processor. That is, computers are specially designed and built to allow copying of files, and this requires different computers to be clones in important respects, or to include specially designed software (such as emulators) that allows 'conversion' of files to the format needed for the local machine environment. Different computers have effectively identical key structures and software, and/or software designed to compensate for precisely known differences in their structures.

Leaving aside the obvious difference in fabrication (e.g., transistors built on silicon versus biological cells bathed in chemicals), there are two very significant differences between electronic computers and human brains. Firstly, no two human brains are identical—each has a unique fine-grained structure. Even human clones (that is, genetic clones, such as monozygotic twins) have many differences in fine brain structure. Secondly, brains are not only organic in terms of fabrication, but in the sense that the fine structure is in constant flux. To the extent that human brains develop the capacity to allow people to communicate through language, this is due to internal processes responding to environmental cues. There is said to be an inherited ability to learn human languages [86], but they still have to be learned by trial and error. Brains develop to get better at exchanging information, but this is a fallible learning process. Of course, humans have evolved to have brains *predisposed* to engage with and learn through culture, but each person still has to acquire the specific symbolic tools, such as those of natural language, de novo.

It might be argued that computers *also* differ at the fine scale and change with use, as the hard-drive fine structure is changed each time a computer is active. However, as pointed out above, the human brain does not have the absolute distinction between the 'processing' and 'memory' faculties, as human learning changes the processing qualities of the brain, not just what is 'stored' (represented) in long-term memory and accessible to conscious reflection.

9. The Constructivist Perspective on Learning as Highly Contingent

From the constructivist perspective, learning is understood to be incremental, interpretive, and thus, iterative [51]. Learning is incremental in the sense that it generally proceeds in modest steps. This follows from characteristics of human cognition: working memory can only mentipulate (that is, mentally 'manipulate') a limited number of 'chunks' of information at once, and novel information is perceived as a sequence of separate chunks of data. New information needs to be well integrated into existing frameworks (a process that takes place over an extended period) before it is robust enough to itself support further new learning.

Learning is interpretive because new material is only understood by being related to prior learning, which may distort the intended meaning. So, learning tends to be iterative—once a particular way to think about some phenomenon or topic is established, then this is likely to shape how new information is perceived, giving it a coherent meaning, thus retaining a consistent perspective. Teachers' intended meanings can become distorted in this process, and existing alternative conceptions may be inadvertently reinforced by teaching that is misunderstood to fit with those existing conceptions, in keeping with the well-characterised human confirmation bias that leads to evidence supporting existing beliefs being preferentially recognised [87].

This is not to say that this outcome is inevitable. Teaching may be ignored (that is, never learned), distorted to fit with existing ideas, hybridised to fit (such that there is some distortion of teaching, but also some shift from prior thinking), added alongside (seen as complementary with, or an alternative view to, or having a non-overlapping range of application to, an existing conception), or may replace prior thinking [55]. However, the constructivist perspective suggests that because sense-making depends on existing thinking, the inherent drive during learning to form a coherent view of the world gives a priority to current (subjective) ways of understanding built into thinking, over 'objective' accounts, regardless of how well established and well evidenced they may be. Conceptual change certainly happens, and teaching can challenge alternative conceptions, but this is not automatically achieved simply by presenting a clear and accurate account of target knowledge [88]. Hence the need for so-called constructivist pedagogies—that is, teaching approaches that take into account the constructivist account of learning and, therefore, take into account learners' ideas.

Educational constructivism offers a model of teaching and learning that suggests human learning is highly contingent on both the learners' cognitive apparatus (e.g., how perception and memory work) and the interpretive resources (including existing knowledge and understanding, vocabulary, epistemological sophistication—such as appreciating the nature and limitations of models and analogies—visual literacy, fund of cultural references, etc.) available to make sense of teaching [59].

10. The Fallacy of Minimally Guided Learning

One especially influential critique of educational constructivism argues that constructivist pedagogy involves minimal guidance from teachers [17]. This critique identified constructivist teaching with open-ended discovery methods. As with any term, 'constructivism' has been used in various ways by a range of authors, but mainstream notions of constructivist teaching are inconsistent with the idea of minimal teacher input. Presumably, this misconception derives from a form of naturalist fallacy: the flawed idea that (i) as constructivism claims that learners necessarily have to construct their own knowledge internally, mentally (that is, there are constraints on what teachers can directly achieve due to the characteristics of human cognition), then (ii) they are best left to their own devices to get on with this, somewhat similar to the hypothetical infinite monkey typing pool that will one day turn out a Shakespeare play. An analogy here might be a building site where the work of constructing houses is undertaken by bricklayers and other trades people, and where recognition that these people do all the construction work leads to the conclusion that the process does not need a site manager or architect (by analogy with a classroom teacher and curriculum designer). Clearly, just because knowledge construction depends upon internal cognitive processes, this does not mean that the direction and rate of that internal construction process cannot be heavily influenced by external processes that help determine the nature, pace, and sequence of information being provided to act as sensory input for the learner's internal cognition.

On the contrary, the constructivist perspective makes it clear that left to their own devices, learners will mostly, at best, tend to simply apply and build upon their existing ideas, including their alternative conceptions. The curriculum presents accounts of the world that are cultural achievements, often built up over generations by leading experts in their fields, and that are quite different from the spontaneous thinking of most people. Education seeks to short-cut the historical development of ideas, and this is only possible using cultural tools (language, graphs, and various other symbolic schemes, such as molecular structure diagrams, circuit diagrams, etc.) and mediation (explanation and argument, modelling, etc.) by those already encultured—such as expert teachers. The constructivist account of teaching and learning was actually developed in response to the non-viability of learners recreating scientific findings by unguided discovery learning [66].

However, the constructivist account also makes it clear that learners, especially younger learners, are not equipped to take in extensive amounts of new information presented by teachers (as in straight lecturing), so constructivist teaching cannot simply be the teacher presenting and the learner listening. Effective teaching requires a lot of teacher guidance, but this is not just 'telling', which will soon overload learners and is likely to lead to misunderstandings. Rather, teaching also requires careful structuring of activities that enable learners to both engage with and explore new learning in modest increments, as well as provide opportunities for teacher monitoring of student thinking [26].

11. Where Teaching–Learning Can Go Wrong

Learners' alternative conceptions are then able to interact with teaching in a number of ways. The two extreme cases would be that a learner adopts the canonical account offered in teaching and no longer brings the prior conception to mind, or teaching has no influence on learner thinking, as the learner's existing alternative conception continues to be activated in all relevant contexts. Both of these extremes may be seen as ideal cases to which real instances likely only approximate. An intermediate situation would be where teaching leads to a partial shift, so the prior alternative conception is modified, but not so much as to match target knowledge. Rather, there is some form of hybridisation of the prior and taught accounts. It is also possible that where teaching is meant to build on prerequisite knowledge, and the learner has an alternative conception of that prior knowledge, then the alternative conception is unchanged, but the teaching is understood in terms of that alternative conception and so is learned in a distorted form. Another possibility is that teaching leads to new learning, which comes to co-exist with an existing preconception, being added to the learner's repertoire of ideas without influencing the existing conception.

This last option may seem unlikely, as it may seem odd to adopt a new conception that is completely at odds with an existing alternative. However, there are two feasible possibilities here. A learner may see logically inconsistent alternatives as offering complementary partial accounts [89]. This is a somewhat sophisticated response, but actually reflects the subtle manner of how models may be used in science [90], and the way models are commonly used in science teaching. As one example, learners are often taught that solids are rigid and virtually non-compressible because they comprise of closely packed molecules, but also that solids expand upon heating because the spaces that exist between the molecules become larger as the molecules move further apart. This stance also reflects the common interpretation from quantum theory that entities, such as electrons, ions, and photons, can be understood incompletely as either particles or waves, but where 'reality' is only partially represented by either of these complementary accounts.

It is also possible that what seem contrary alternatives to the expert (such as a teacher or educational researcher) are understood by the learner to have non-overlapping ranges of application—that is, scenarios and contexts that are considered formally equivalent to an expert may seem unrelated to the learner [78]. In addition, it has been found that learners commonly acquire formal accounts of concepts that they apply in the context of the classroom or examination hall while retaining a different way of thinking to apply in everyday contexts [91]. This does not imply this is necessarily a deliberate strategy, rather different contexts cue and activate somewhat distinct knowledge representations. So, learners who 'know' in class that energy is always conserved, and apply this in formal tests, may engage in playground talk about how running around gives them energy. This can be seen as an example of how people engage in multiple different discourses, and this may even be seen as functional, allowing effective lifeworld engagement with peers, but adoption of formal conceptions in academic scenarios. After all, even a Nobel-prize-winning physicist might tell her children to close the door on a wintery day so as not to let the cold in.

From the constructivist perspective, teaching–learning can be understood as a system where the teachers have to represent their internal thoughts into symbols in the public space that learners then need to interpret in order to make sense of teaching [85]. Within this model, we can distinguish knowledge, in the sense of understandings of aspects of the world that constructivists posit to, in some sense, exist in the minds of individuals, from the information contained in the public representations (the teacher's speech, a textbook figure, etc.). Information (data) does not inherently contain meaning, but requires a knowing subject to interpret. In a sense, the teacher's job involves coding features of her knowledge using a symbolic code that learners can then decode. A crude analogy would be the streams of binary data, strings of 0 s and 1 s, used to copy information between computers. But, as suggested above, a key way in which people differ from computers is that the latter are designed with built-in protocols to ensure that data are decoded to reconstruct precisely what was initially coded, whereas people grow organically and learn to decode communications somewhat by trial and error.

From this system perspective, there are three main classes of outcomes of a teaching episode:

- the learner interprets teaching to construct an understanding that is reasonably close to the target knowledge,
- the learner fails to understand teaching,
- the learner interprets teaching to construct an understanding that is inconsistent with the target knowledge.

The learner may fail to understand teaching because she is lacking the expected interpretive resources: some prerequisite knowledge is lacking. The learner may also fail to understand teaching when the pertinent prerequisite knowledge has been previously learned but is not brought to mind, as the learner does not recognise its relevance.

As suggested above, a learner may understand differently than intended because instead of relating teaching to the expected prerequisite knowledge, they hold an existing alternative conception of the topic phenomenon. However, learners may also understand differently than intended because they make sense of teaching in terms of interpretive resources that are not relevant from the canonical perspective. So they perceive a link with some prior learning that offers them a way of understanding teaching that is quite different from that intended (perhaps forming a new alternative conception).

Such 'bugs' in the teaching–learning system are likely to occur unless a teacher can sufficiently anticipate how learners will make sense of teaching so as to present information in ways that will be interpreted ('decoded') as intended [92]. This, in turn, relies on the teacher having a mental model of the learners' interpretive resources in terms of prior learning, vocabulary, graphical literacy, existing alternative conceptions, and so forth, that sufficiently matches the learners' actual available interpretive resources, allowing the teacher to anticipate correctly. In practice, teachers' abilities to anticipate how learners will interpret teaching will always be limited, as each learner in a class has a complex, evolving, and unique set of interpretive resources for making sense. Therefore constructivist pedagogy includes an interactive aspect for the teacher to continually monitor learner thinking.

12. Constructivist Pedagogies

There are many teaching approaches and techniques that have been labelled as constructivist, and sometimes these are seen to overlap with approaches described as 'active learning' [93], 'student-centred' [94], or those that in some contexts are referred to as 'reform' pedagogies [95]. In particular, constructivist approaches align with recommendations for dialogic teaching, where alternative ideas, and especially learners' own ideas, are elicited and actively considered, explored, and compared [96,97]. Dialogic teaching shifts between exploratory phases, where different perspectives are tested against evidence and arguments, and more traditional teacher talk that uses rhetorical skills to help construct the canonical accounts with learners [98].

Classroom dialogue is, therefore, a key feature of the constructivist classroom, both in the sense that teacher talk does not dominate the classroom, and in a propensity of activities where learners are expected to engage in discussion in groups small enough for all to contribute. Such activities can be effective in moving learner thinking on: when they are well designed, and when learners have the skills to engage in 'productive' talk that genuinely explores focal issues and leads to shared construction of arguments [99]. This will not be automatic with younger learners [100] and may require some initial teaching focusing on key skills, such as effective listening and learning to build on what others have said [101].

For a teaching approach to be considered as 'constructivist', it needs to respond to the nature of learning as incremental, interpretive, and iterative. That is, it needs to take into account (i) the modest amount of unfamiliar material that can be learnt at any time, and how robust learning is not an all-at-once process; (ii) how knowledge cannot be copied from mind to mind, but has to be built up by making sense of information in terms of the available interpretive resources; (iii) how learners often have existing alternative conceptions contrary to the target knowledge represented in the curriculum; (iv) how teachers need to monitor the sense being made by learners of teaching.

Key features of constructivist teaching [26] include the following:

- Establishing learners' starting points (pre-testing to check on expected prior learning) and making existing thinking, such as alternative conceptions, in a topic explicit.
- Breaking down target knowledge into 'learning quanta' that are manageable from learners' perspectives (not overloading working memory), and sequencing material to build up from learners' prior knowledge.

- Organising the teaching of complex topics in terms of successively more sophisticated treatments in different grade levels—an approach called 'the spiral curriculum' [43].
- Seeking the optimal level of simplification—simplifying material sufficiently for learners to make sense of it but avoiding oversimplification that loses what is central to target knowledge.
- Making the unfamiliar familiar—direct hands-on experience is ideal, but where this is not possible then through media, models, diagrams, analogies, similes, etc.
- Dialogic teaching presentations that acknowledge and explore learner thinking as well as canonical target knowledge [102].
- Giving learners opportunities to explore and work with new ideas before moving on—commonly, this will be based on working in small groups, where learners are expected to discuss their ideas.
- Seeking to balance the challenge of learning activities (important to support substantive development) and differentiated support, such that all learners are helped to make (and feel) progress in learning [103].
- Frequent opportunities for the teacher to acquire feedback on how teaching is being understood—that is, formative assessment [104].
- Regular reinforcement of new learning ('drip-feeding'), especially core ideas, to consolidate learning.

The constructivist classroom (depending on the grade level) is likely to feature periods of teacher-led presentations, but these will consider elicited student thinking as well as the accounts to be taught, and they will usually be quite short episodes interspersed with other kinds of activities. The primary purpose of explicitly considering learners' ideas is to allow learners to compare their thinking with the target knowledge and to be persuaded of the merits of the canonical accounts. Constructivist teaching shifts through sequences of classroom episodes, from such dialogic episodes to reaching a (hopefully) negotiated authoritative position aligned with the target knowledge [97].

A few illustrative examples of activities that might be included in constructivist teaching would be:

- Concept cartoons [105], which show a number of individuals disagreeing about the nature of some phenomenon (often representing target knowledge and several widely reported alternative conceptions), where small groups of learners debate the merits of the different positions.
- Predict–observe–explain, where a small group has to predict the outcome of some manipulation (e.g., changing the length of the string of a simple pendulum) before trying the activity, and then explain what was observed.
- Devising a dramatic physical simulation of some phenomena [106] (such as the diffusion of ink dropped into water).

Activities are often based around small group discussion work and may commonly have some material outcome (such as a poster, a video, or a model), or be focussed on problem-solving. Constructivist teaching is associated with a focus on enquiry, although such enquiry needs to be carefully managed by the teacher to channel learner thinking, as entirely open-ended enquiry is unlikely to be productive except with the most advanced learners. (The predict–observe–explain activity exemplifies one approach to structuring enquiry such that learners are supported in productive activity.) Those approaches that involve group creation of products for dissemination (a wall poster, a presentation to the class or to a community group, etc.) are confusingly sometimes denoted as constructionist [107], though this does not necessarily imply adherence to the principles of social constructionism discussed above.

Constructivist approaches in higher education may replace teaching based on lecture courses with learning through, for example, group projects or problem-based learning. Teaching may be 'flipped' so that, rather than lectures, class time is spent on activities based on learners applying material they are assigned to study in advance [108]. However, where lecture courses are retained, it is still possible to build in interactivity in terms of both breaking up the presentation to intersperse short activities to allow students to work with new ideas being presented, and including opportunities for the lecturer to test students' understanding of key points [26].

Considering the diversity in the ways in which terms, such as constructivism and constructionism, are used by different authors, judgements about the extent to which a classroom is constructivist, or whether a teacher adopts a constructivist teaching approach, should be based on the presence or absence of the key features listed above.

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