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Conceptual change and knowledge integration as learning processes in higher education: A latent transition analysis☆

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A B S T R A C T

Conceptual change, that is, a restructuring of incompatible prior knowledge, is a well investigated learning mechanism in school children's acquisition of new concepts. An understanding of academic concepts is also a central learning goal of higher education. However, there is almost no research on conceptual change and knowledge integration in higher education. We tracked 137 undergraduate psychology students' concepts of human memory longitudinally over four semesters. A latent profile transition analysis (LPTA) showed that the students' development followed six transition paths between four knowledge profiles. These developmental pathways were well-ordered, indicated a general trend from fragmented knowledge to integrated scientific knowledge, and correlated with the students' university grades and with an additional test of memory understanding. The findings highlight the importance of conceptual change, in particular, knowledge integration in higher education, and exemplify the usefulness of LPTA for modeling individual differences in longitudinal changes of multidimensional knowledge structures.

1. Introduction

Students' understanding of academic concepts, for example, force in Physics, supply and demand in Economy, or human memory in Psychology, is a central learning goal of higher education. Conceptual understanding is a cornerstone of professional expertise (Tynjälä, 1999). It helps learners make predictions, explain observations, reason about the interrelations of facts, infer new knowledge, choose between alternative procedures, and construct new problem solving strategies (Goldstone & Kersten, 2003; Machery, 2010; Rittle-Johnson, Schneider, & Star, 2015). Accordingly, the European Qualification Framework for Lifelong Learning lists "advanced knowledge of a field of work or study, involving a critical understanding of theories and principles" (European Commission, 2008, p. 12) as a central qualification for reaching a Bachelor's degree.

In many cases, conceptual change, that is, a restructuring of the learner's prior knowledge, is a necessary part of acquiring new conceptual knowledge (Carey, 1985; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 2008). Prior knowledge guides and constraints the interpretation of new knowledge and its encoding in memory. It often stems from observations and explanation attempts in everyday life outside formal instruction and thus can be incompatible with the scientific concepts to be learned (Carey, 1992). This explains why acquiring an understanding of academic concepts can be so difficult. Conceptual change is investigated by educational, developmental, cognitive, and philosophical scientists, who found the approach productive in content domains as diverse as physics, chemistry, biology, mathematics, medicine, and the social sciences (M. Schneider, Vamvakoussi, & Van Dooren, 2012; Vosniadou, 2008). Some of the past findings have direct implications for the design of effective learning environments, for example, school instruction (Duit, Treagust, & Widodo, 2008), professional development programs for teachers (e.g. Hewson, Tabachnick, Zeichner, & Lemberger, 1999), and projects to foster instructional quality in schools (Beeth et al., 2003).

Empirical research on conceptual change of students in higher education is virtually non-existent, despite the importance of academic concepts as learning goals in higher education. Almost all studies on conceptual change focused on students in K-12 schools or even younger children. In the present study, we examined to what extent conceptual change is still a relevant learning mechanism in higher education and whether it leads to similar developmental patterns in higher education as it does in K-12 school learning. We expected conceptual change to

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still be relevant in higher education, because learning by conceptual change has been described as a general human learning mechanism that is relevant independently of age group and content domain. For example, there are some similarities between children's thinking processes when acquiring new concepts and scientists' thinking processes when developing a new theory, which hints at an age-general importance of conceptual change (Gentner et al., 1997).

1.1. Knowledge fragmentation and integration

Research with school-aged children found that the fragmentation and integration of knowledge are two central component processes of conceptual change (e.g., M. Schneider & Hardy, 2013). Networks of conceptual knowledge in long-term memory can comprise types of elements, such as observations, hypotheses, explanations, analog mental models, mental images, category exemplars, and subjective theories (Goldstone & Kersten, 2003; Machery, 2010). These elements have been acquired in situation as diverse as conversations with peers, everyday-life observations, internet videos, school instruction, books, or movies. Learners do not always understand how these different and sometimes even conflicting pieces of knowledge relate to each other, and store them independently in long-term memory. This leads to fragmented knowledge.

Another source of knowledge fragmentation is the fact that storing correct concepts in long-term memory does not necessarily erase related misconceptions. Converging evidence from reaction times studies with sentence verification tasks (Potvin, Masson, Lafortune, & Cyr, 2015; Shtulman & Valcarcel, 2012), multiple choice tests (M. Schneider & Hardy, 2013), and interviews (diSessa, Gillespie, & Esterly, 2004) shows that naïve misconceptions and scientifically correct concepts or parts thereof can co-exist in long-term memory and do so frequently, not only in children, but also over the life-span (Shtulman & Harrington, 2016). Pieces of fragmented knowledge are activated dependent on the context (diSessa et al., 2004), so that learners do not necessarily realize when they hold pieces of knowledge in long-term memory that support or contradict each other.

Thus, the integration of pieces of knowledge into a coherent overarching knowledge structure is an important aim of instruction (Linn, 2006; M. Schneider, 2012). This can include connecting previously isolated pieces of knowledge in memory and subsuming previously unrelated concepts under a general principle. Understanding these relations can help students to differentiate better between normatively correct and incorrect ideas, thus, leading to more homogeneous and more correct knowledge. Teachers can stimulate knowledge integration by eliciting students' knowledge, adding new normative concepts, helping students to develop criteria for evaluating alternative conceptions, and by encouraging students to compare the alternatives and to sort out inadequate conceptions (Linn, 2006).

1.2. A latent profile transition analysis of fragmented and integrated knowledge

Developmental patterns of co-existing pieces of knowledge can be investigated by latent profile transition analyses (LPTA), as demonstrated by three studies with school children on knowledge development in mathematics and science (Kainulainen, McMullen, & Lehtinen, 2017; McMullen, Laakkonen, Hannula-Sormunen, & Lehtinen, 2015; M. Schneider & Hardy, 2013). M. Schneider and Hardy (2013) investigated third-graders' understanding of floating and sinking of objects in liquids. The children participated in several sessions of either (1) a constructivist learning environment with a high degree of instructional support given by the teacher, or (2) a constructivist learning environment with a low degree of instructional support, or (3) a baseline control group without instruction on the topic (see Hardy, Jonen, Möller, & Stern, 2006, for details of the interventions). Before and after the instruction as well as one year later the children indicated in a multiple choice test how strongly they agreed with a number of statements. Each statement described (a) a common misconception, (b) an everyday life explanation, which has some explanatory power in everyday life but does not hold up to systematic scientific evaluation, or (c) the relevant scientifically correct concepts. The three sum scores indicating how often each child agreed with misconceptions, everyday conceptions, or scientific concepts were used as indicators of latent profile memberships at the three measurement points in a latent profile transition model. The parameters of this model were estimated so that the similarity of the scores of persons grouped in the same latent profiles was maximized and the similarity of the scores of persons grouped in different latent profiles was minimized (see Hickendorff, Edelsbrunner, McMullen, Schneider, & Trezise, this issue, for methodological details). Thus, the latent profiles indicated groups of learners who had the same configuration of misconceptions, everyday conceptions, and scientific concepts. In addition to the profile characteristics and memberships at each measurement point, the model estimation also yielded the frequencies of the profile transitions over time. These were interpreted as pathways of conceptual change.

The model results in the study by M. Schneider and Hardy (2013) indicated five latent classes. Some of these had mean score profiles that indicated integrated knowledge, that is, high profile mean scores for misconceptions only or for scientific concepts only. Other profiles indicated fragmented knowledge. In these profiles, two or three of the scores for misconceptions, everyday concepts, or scientific concepts were higher than the sample mean. Most participants were on one of seven developmental pathways between these five profiles over time. These transition paths indicated a general trend from misconceptions and fragmented knowledge towards more correct and integrated knowledge. However, there were strong individual differences. Knowledge fragmentation increased on some paths and decreased on others. About 20% of the children still had fragmented knowledge, that is, co-existing misconceptions, everyday concepts, and scientific concepts, even one year after participating in the constructivist learning environment. The instructional condition was related to the frequency of the transition paths. The constructivist learning environment with a high degree of instructional support led to the most integrated knowledge and the untreated control group to the least.

The other two studies using latent transition analyses to investigate knowledge development traced school students' knowledge of rational numbers over time (Kainulainen et al., 2017; McMullen et al., 2015). Similar to M. Schneider and Hardy's findings, students' knowledge of rational numbers was captured by a small number of knowledge profiles and systematic transition paths between these profiles over time, some of which could be interpreted in terms of conceptual change. However, the generalizability of these findings to other age groups and content domains remains unclear (cf. Edelsbrunner, Schalk, Schumacher, & Stern, this issue; McMullen, Van Hoof, Degrande, Verschaffel, & Van Dooren, this issue).

1.3. Is conceptual change still relevant in higher education?

In the current study, we used latent profile transition analysis to investigate whether conceptual change and, more specifically, knowledge fragmentation and integration still can be found in higher education and whether their quality is related to the learning outcomes, that is, students' grades. There are at least three reasons to expect that this might not be the case. First, students in higher education successfully participated in school instruction, perhaps leading to a firm fundament of correct and integrated knowledge that higher education can build on. Second, students in higher education tend to have better developed meta-cognitive strategies than school children (Weil et al., 2013). Thus, they might be able to monitor, identify, and understand the confirmatory or contradictory relations between their prior knowledge and the knowledge to be learned making knowledge integration a trivial process. Finally, arguably, the content of higher