**Why educational research needs a complex system revolution that embraces individual differences, heterogeneity, and uncertainty**

**Abstract**

Whereas the field of learning analytics has matured, several methodological and theoretical issues remain unresolved. In this chapter, we discuss the potentials of complex systems as an overarching paradigm for understanding the learning process, learners and the learning environments and how they influence learning. We show how using complex system methodologies open doors for new possibilities that may contribute new knowledge and solve some of the unresolved problems in learning analytics. Furthermore, we unpack the importance of individual differences in advancing the field bringing a much-needed theoretical perspective that could help offer answers to some of our pressing issues.

# Introduction

Learning analytics (LA) has emerged to harness the opportunities created by the abundance of data and advanced machine learning methods to improve learning and teaching and offer the much-needed personalized support. The premise was that the availability of massive amounts of data would enable novel insights, improve inferences, and deliver real-life impact Siemens\_2013. A wide array of learning analytics applications has been developed over the years to realize such aspirations. One of the initial applications of learning analytics focused on predictive modeling: that is, collecting data of online activities, such as clicks, access to educational resources, or forum discussions to create a predictive model that would early flag underachievers. The early identification of an underachieving student in a course paves the way for proactive intervention Ifenthaler\_Yau\_2020. Several studies have reported the successful identification of underachievers in individual courses or limited samples. Yet, transferring such models across programs or courses has been a consistent disappointment. All the more so, very few have reported a successful proactive intervention Ifenthaler\_Yau\_2020.

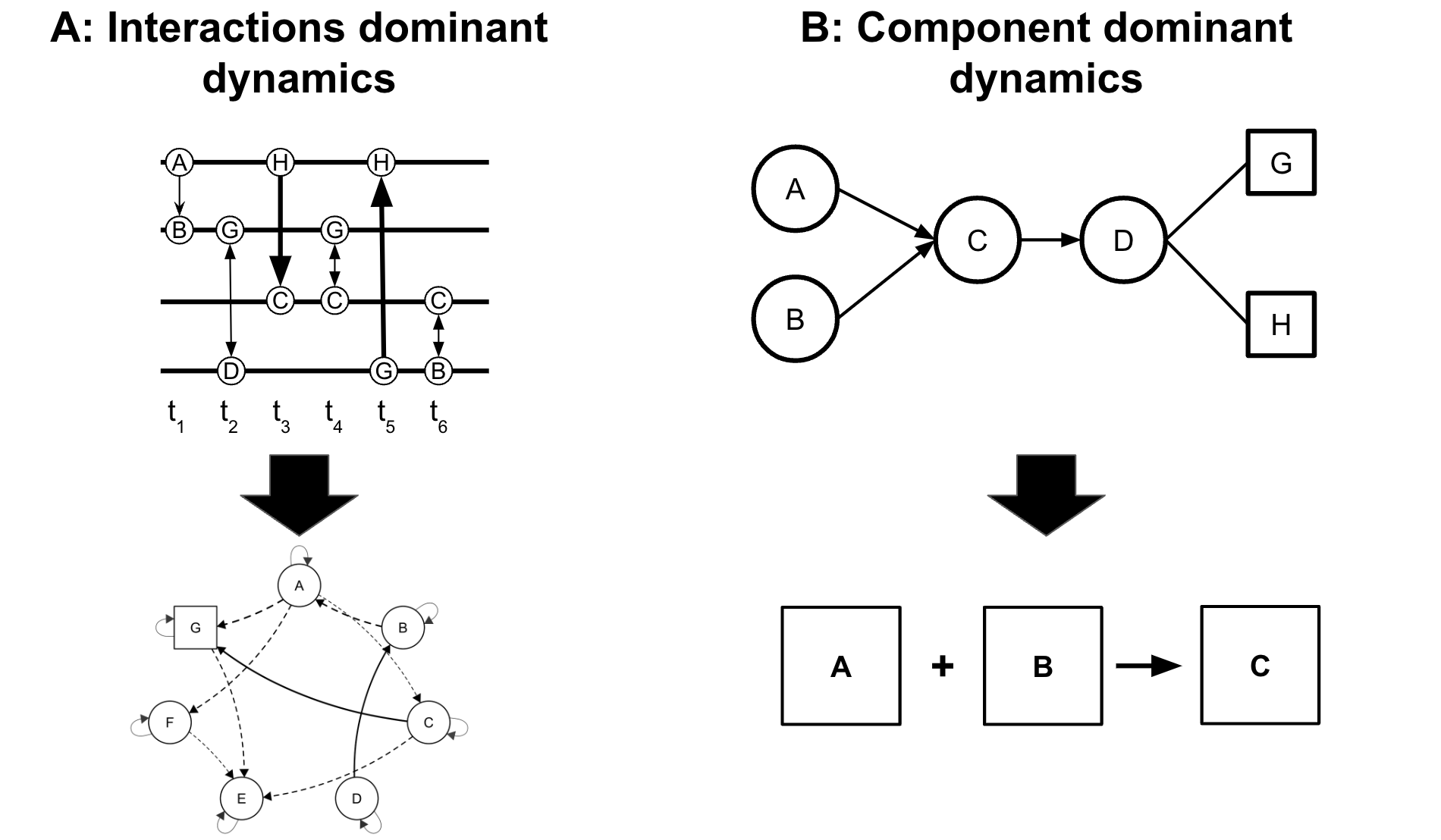
A recent massive study with data from 250,000 students tried to examine the effectiveness of a large-scale, evidence-based intervention, and reported small benefits. The researchers concluded that interventions are likely more effective when implemented for the right person, at the right moment in time. In fact, such a conclusion is far from new, Gordon Paul's stated in 1967 that the important question is “What treatment, by whom, is most effective for this individual with that specific problem, and under which set of circumstances?”Paul\_1967. This requires predictions at a dynamic (i.e., time-varying) and individual level Kizilcec\_Reich\_Yeomans\_Dann\_Brunskill\_Lopez\_Turkay\_Williams\_Tingley\_2020. Another recent large-scale study showed that a low proportion of variance in students’ performance was explained by the behavior-based indicators Jovanović\_Saqr\_Joksimović\_Gašević\_2021, and thus, students should best be identified on internal conditions (e.g., knowledge, self-regulation, and motivation). Recent reviews of intervention using LA methods further emphasize the difficulty of these promises Larrabee Sønderlund\_Hughes\_Smith\_2019. As Du et al. (2021) stated that “every course has different course requirements, it is impossible to identify generalisable thresholds of individual behaviors across courses” (p. 510). This holds even when courses are similar, homogenous, and use the same teaching Saqr\_Jovanovic\_Viberg\_Gašević\_2022.

The lackluster of predictive LA has led to a wide range of research threads aiming to tap into other methods that help explain and optimize students’ learning. Such methods have been used to analyze the relational temporal patterns of students’ learning processes. For instance, building on the importance of time, Process Mining (PM) and Sequence Analysis (SM) have gained wide popularity in the analysis of online learning activities to explain the time-ordered patterns of learning activities and to capture patterns of learning strategies Saqr\_López-Pernas\_Jovanović\_Gašević\_2023. Social network analysis (SNA) has also gained renewed interest and wider application in collaborative learning settings to understand students’ roles and interaction patterns and to find SNA measures that help predict performance Saqr\_Elmoazen\_Tedre\_López-Pernas\_Hirsto\_2022\_Saqr\_Poquet\_López-Pernas\_2022. Nevertheless, most of such methods —which we covered with examples in the book— require an overarching framework or a theoretical underpinning to better ground the analysis. In this chapter, we discuss the importance and potential of complex systems in understanding learning, learners, and the educational milieu at large.

# Complex systems and education

Most learning theories and frameworks can be conceptualized as systems, that is, composed of multiple components, phases, or elements that interact with each other. Typically, such interactions are non-linear and vary across people, contexts, and time scales resulting in the emergence of a unique learning process Jörg\_Davis\_Nickmans\_2007\_Koopmans\_2020\_Ladyman\_Lambert\_Wiesner\_2013. For instance, engagement can be considered as a complex system. Engagement is then viewed as the result of interaction between different components, namely behavioral, cognitive, and emotional dimensions Reschly\_Christenson\_2022\_Wang\_Fredricks\_2014. Such interactions vary between tasks, times, and contexts which are often referred to as *interaction-dominant systems* (Figure 1B) Hilpert\_Marchand\_2018\_Van Orden\_Holden\_Turvey\_2003. In interaction-dominant systems, the relationships between componentsmaychange intensity and direction across times and situations. For instance, a student may enjoy school in the early days which drives their engagement and achievement and boosts their motivation. These dynamics may change over time, where achievement could be the driving force of future engagement but also results in anxiety rather than enjoyment. In turn, anxiety may negatively affect school enjoyment and engagement. This dynamic view is more realistic than the common b*ox-and-arrow* models where the components of the system are rigidly assembled in a stable manner and the relationships between the components are deemed to be linear (Figure 1B). Viewing the previous example from a linear perspective would entail that we see that the student will always have a stable relationship: enjoyment always drives engagement and achievement with little changes in the future nor any new patterns emerge. A linear view of engagement is then far from realistic.

Engagement follows Gestalt principles, meaning that engagement is considered more than just the sum of its parts (i.e., engagement ≠ emotions+cognition+behavior) Wang\_Fredricks\_2014, the interactions between these components are often multiplicative rather than simple linear sum and rely on the environment and contextual conditions (family, peers, teachers, school, etc.). Additionally, most engagement theories describe feedback loops (for instance, achievement drives further engagement and vice versa) Tinto\_2022. Again, such feedback loops fit well with the salient features of a complex dynamic system Ladyman\_Lambert\_Wiesner\_2013.



**Figure 1.** A complex dynamic system where the interactions vary across time, change direction and strength in a soft-assembled manner. B. A box and arrow framework where the interactions are fairly stable and linear.

Self-regulated learning (SRL), too, follows complex systems principles: the interaction between SRL phases across different learning scenarios and temporal scales results in unique learning strategies which are different mixtures of SRL phases. Such interactions may enhance, impede, or catalyze each other. For example, reflection on performance can lead to improved learning and better goal-setting in a student. In another student, reflection can lead to frustration, and low performance. We can expect vast amounts of variations and complex interactions in the same way. Such conceptualization of SRL as a state of a complex person-environment system is necessary to understand the interplay of the intricate SRL process Hilpert\_Marchand\_2018\_Koopmans\_2020. Indeed, Boekaerts and Cascallar 2006 argue that it is impossible to understand learning and achievement “unless one adopts a systems approach to the study of self-regulated learning”. Similarly, other SRL theoreticians share the same conceptualization. For instance, Zimmerman\_Risemberg\_1997 states that SRL is “a complex system of interdependent processes” Zimmerman\_Risemberg\_1997, and so did Winne et al. when they described engagement as complex and dynamically changeable across contexts Winne\_Zhou\_Egan\_2011.

In fact, many learning concepts have been already described, operationalized, and framed in complex system terms including motivational Papi\_Hiver\_2020\_Yuan\_Zhen\_2021, achievement motivation theories Urdan\_Kaplan\_2020, agency Deakin Crick\_Huang\_Ahmed Shafi\_Goldspink\_2015, and metacognition theories Vollmeyer\_Rheinberg\_1999. Also, the student has been described as a complex system Brown\_1997, so have small collaborative groups Mennin\_2007, and the classroom as a whole to list a few. The merit of this complex systems view is that it not only accounts for many of the features of learning-related processes (e.g., being interaction-dominant, lacking central control) but also provides a framework for better understanding - and perhaps even predicting - such processes Koopmans\_2020. Nevertheless, endorsing that a system is interaction-dominant means that we also understand that forecasting and prediction of the system's future status may be more uncertain than the simple linear dynamics of component-dominant scenarios Wichers\_Schreuder\_Goekoop\_Groen\_2019. That is, the slightest change in initial conditions may lead to substantial differences in the end state (a phenomenon called “sensitive dependence on initial conditions”). It follows that in order to understand complex systems, one has to look into the dynamics of such systems.

## Dynamics in complex systems

The interactions that maintain a complex system tend to give rise to relatively stable configurations, which can be considered attractor states that emerge again and again Scheffer\_2009 Attractors can take many different forms, ranging from chaotic to cyclic to simple point attractors. In the context of learning analytics, for instance, a point attractor could resemble a state of “being relatively engaged”. Importantly, the attractors of complex systems may change over time. The aforementioned point attractor could for instance gradually lose its strength, up to a point where the attractor disappears. When reaching such a tipping point, the system switches to an alternate attractor Scheffer\_Carpenter\_Dakos\_van Nes\_2015. Such a shift between different attractors is often labeled a transition. Transitions can be harmful - e.g., reflecting a shift from an adaptive state towards a maladaptive state - or beneficial - e.g., reflecting a reverse shift. Relatively well-investigated dynamics are “critical transitions”, which entail a shift from one stable regime (i.e., point attractor) towards another regime Scheffer\_2009 (i.e., other point attractor). For instance, countries can shift between a state of peace towards a state of war and the climate can shift from a greenhouse to an icehouse state Similarly, a learning child may shift between a state of engagement towards a state of disengagement. An important premise of complex systems theory is that such transitions - albeit in very different systems - follow the same generic principles. Among these principles is the idea of critical slowing down Scheffer\_Bascompte\_Brock\_Brovkin\_Carpenter\_Dakos\_Held\_van Nes\_Rietkerk\_Sugihara\_2009\_Wichers\_Schreuder\_Goekoop\_Groen\_2019. Critical slowing down describes that, prior to a critical transition, it becomes increasingly difficult to recover from perturbations Scheffer\_Bascompte\_Brock\_Brovkin\_Carpenter\_Dakos\_Held\_van Nes\_Rietkerk\_Sugihara\_2009\_Scholz\_Kelso\_Schöner\_1987*.* In the case of engagement, such perturbations can be school problems (e.g., problems with other pupils). When the student is in a stable, engaged state - and thus, unlikely to experience a transition towards a disengaged state - such perturbations only have a brief effect on the student’s attention. This means that, upon a perturbation, he/she quickly recovers his/her “baseline” engagement levels Masten\_Nelson\_Gillespie\_2022. As the resilience of the engaged state declines, however, the student becomes increasingly affected by these perturbations. This means that recovering his/her normative engagement becomes more and more difficult. This in turn translates to altering system dynamics, meaning that the interactions between and within system elements changes. Monitoring such changes may then allow for anticipating otherwise unpredictable transitions in learning processes Scheffer\_Bascompte\_Brock\_Brovkin\_Carpenter\_Dakos\_Held\_van Nes\_Rietkerk\_Sugihara\_2009\_Scholz\_Kelso\_Schöner\_1987\_Wichers\_Schreuder\_Goekoop\_Groen\_2019. Ultimately, this could aid the prevention of harmful transitions or the fostering of beneficial transitions.

An important implication of viewing transitions in learning processes through a complex systems lens is that declining resilience may be detectable *within* systems, which in this case means that inferences are made on the level of the student. This approach contrasts with the common group-level inferences, which may allow for telling *who* is likely to undergo a transition. For instance, group-level approaches may lead to the notion that “individuals with this behavior, this personality, or this socio-economic background are more likely to drop out of school than others”. Within-individual approaches, in contrast, may allow for determining *when* a specific individual will drop out. For the purposes of targeted and timely intervention, such insight is invaluable. A related merit of complex systems principles is that they allow for personalization. For instance, it is likely that vulnerability to major changes (e.g., transitions in engagement, school drop-out) manifests in different variables for different individuals. Because declining resilience can be monitored within individuals, such heterogeneity does not pose a challenge. Rather, it can be accommodated by monitoring resilience in those variables that are considered most relevant for this particular student, in this specific context Olthof\_Hasselman\_Aas\_Lamoth\_Scholz\_Daniels-Wredenhagen\_Goldbeck\_Weinans\_Strunk\_Schiepek\_et al.\_2023. In conclusion, the possibility to monitor generic indicators of declining resilience may pave the way for deriving person-specific insights in predicting (and potentially, preventing or stimulating) changes in learning-related processes.

## From theory to practice: measurement and analyses

If we agree that the learning phenomena, process or construct can be conceptualized as states in a complex system, then it becomes essential that a complex system lens is used to map the structure and dynamics of the said phenomena Olthof\_Hasselman\_Oude Maatman\_Bosman\_Lichtwarck-Aschoff\_2023. This has profound consequences for both measurement and data analyses. With respect to measurement, a complex systems lens necessitates the collection of time series data. The reason is that systems - and the interactions between elements within those systems - are by definition time-varying, and it is precisely the changes over time that contain information about the system as a whole. Thus, instead of a single, cross-sectional measurement, a complex systems perspective requires collecting repeated measurements for each individual. With advancing technology, collecting such measurements has become increasingly feasible. Broadly speaking, we can distinguish between passively collected data - which includes mobile sensing data (e.g., typing speed, scrolling, app usage, and sometimes also location) and actigraphy data (e.g., movement, heart rate, skin conductance) - and self-reported data - which is gathered through repeatedly prompting students with a questionnaire on their mood, motivation, or other psychological variables. Both modalities have their pros and cons. The main benefit of passively collected data is the amount of data that can be collected without burdening participants. The other side of the coin is that this amount of data often needs aggregation and intensive cleaning, which is far from straightforward, and in that sense the data can be “hard to handle”. The main benefit of self-report data is that the content of measurement may be more closely related to the construct of interest. However, self-report data require considerable motivation from participants, and it is not inconceivable that such demanding research designs introduce sampling bias. Put differently, it is possible that the types of individuals who engage in studies involving long-term self-reports are not representative of the general population (e.g., in terms of conscientiousness Scollon\_Kim-Prieto\_Diener\_2003). At the same time, however, studies that investigated sampling bias in intensive longitudinal studies involving the collection of repeated self-reports did not find evidence for self-selection Schreuder\_Groen\_Wigman\_Wichers\_Hartman\_2023. As intuitive as it may seem, scientific evidence for the self-selection of participants into intensive longitudinal studies is thus lacking. Besides these relatively practical considerations, the necessity of time series data also comes with more fundamental questions, for instance, related to the timescale of assessments. Ideally, this timescale should be informed by the timescale at which the system’s dynamics unfold. This in turn varies between constructs: engagement may shift over minutes, while student’s performance may shift over weeks.

Naturally, the focus on time series data has consequences for the analyses that are useful. Not only do we require time series analyses —which can handle the temporal dependency in the data— but we also need methods that can capture nonlinear and person-specific trends. This is because the dynamics of complex systems are typically non-linear, as illustrated by the erratic behavior and sudden shifts that govern complex systems. Examples of such analytical methods include dynamic time-warp analyses, generalized additive models, recurrence quantification analysis, state space grids, and moving window analyses Hilpert\_Marchand\_2018. Despite that most learning theories and processes can be described in complex system terms and the long history of theoretical foundations of complex systems in learning sciences, learners’ and learning environments, the uptake of suitable methods and approaches is lagging behind Hilpert\_Marchand\_2018\_Koopmans\_2020. Furthermore, applications, framing, and operationalization of learning theories as complex systems are rare in educational research Hilpert\_Marchand\_2018\_Koopmans\_2020. In this book, we therefore provide some theoretical underpinnings of a complex systems perspective on learning and education, and we further included several chapters that deal with methods and analyses that accommodate a complex systems lens e.g., psychological networks, Markovian models, and model-based clustering. In other fields, the adoption of such methods has resulted in the renewal of theories, understanding of human behavior, and the emergence of new solutions to real-life problems Borsboom\_Haslbeck\_Robinaugh\_2022\_Quintana\_2023. Our aim was to help interested researchers to embrace such methods in their analysis.

## Complex systems and individual differences

Complex systems —as a paradigm— facilitates a better understanding of the heterogeneity and individualized nature of human behavior and psychological phenomena. In fact, many complex system methods, some of which described earlier, have a strong emphasis on person-specific fine-grained dynamics. The next section will offer a more in-depth discussion of the individual mechanisms and how they relate to the general average assumptions.

### The Individual

The “individual”, or the “self” is a central construct in several learning theories, methodologies, and approaches. For instance, self-regulated learning, self-concept, self-control, and self-directedness to mention a few Panadero\_2017. Further, the literature is awash with the notion of personalization, student-centeredness, and adaptive learning. Nonetheless, research is commonly conducted using methods that essentially ignore the “individual” process. In that, research is performed using what is known as variable-centered methods where data is collected from a “group of others'' to derive generalizable laws. In variable-centered methods, researchers compute standard tendency measures (mean or median) from a sample of individuals (often referred to as group-level analysis) to derive “norms” or “standard recommendations”. The average is considered a “norm” where everyone is assumed to fit. What is more, the outcome of such analysis is deemed representative and therefore, generalizable to the population at large. Given that such an average is derived from a sample of others, it rarely represents any single student Fisher\_Medaglia\_Jeronimus\_2018\_Winne\_2017. An accumulating body of evidence is mounting that humans are heterogeneous with diverse behaviors, attitudes, cognition, and learning approaches. Thereupon, using insights based on group-level analysis has so far resulted in recommendations that don’t work, assumptions that fail to hold, and replications that are hard to obtain. Furthermore, intervention programs or procedures based on such samples offered no more than negligible effects, e.g., Kizilcec\_Reich\_Yeomans\_Dann\_Brunskill\_Lopez\_Turkay\_Williams\_Tingley\_2020.

The fact that group-level analysis is less representative of the person is far from new and has been recognized for decades. Yet, the methods that are more suited for person-specific analysis may have not progressed fast enough. The last two decades have witnessed a revolution in data collection methods, statistical approaches, and procedures that allow such analysis, collectively known as person-specific analysis. In many ways, person-specificmethods are a paradigm shift in research which according to Molenaar\_Campbell\_2009 represent a “brink of a major reorientation” that is “no longer an option, but a necessity”. Endorsing a person-specific approach may change how research is performed and how findings are applied Saqr\_2023a\_Saqr\_Lopez-Pernas\_2021. The person-specific methods —being individualistic— have low potential for generating generalizable recommendations Saqr\_2023a. Therefore, a combination of group-level and person-specific methods may be the best way forward. Such a combination may augment our understanding and provide precise interventions **at the high resolution of the single student** and sharpen our insights of the group level that are generalizable to the wider population Epskamp\_Waldorp\_Mõttus\_Borsboom\_2018.

There is an abundance of digital tools and data collection methods that allow the gathering of fine-grained intensive data about students. Such data -where several measurements from the same person are gathered- can allow the analysis of more person-specific insights. In doing so, it can help obtain an accurate view of a student's learning processes and offer more precise personalized support Molenaar\_Campbell\_2009\_Saqr\_2023a\_Saqr\_Lopez-Pernas\_2021.

### Heterogeneity

As discussed in the previous section, a central assumption of group-level analysis is that “the average individual” represents every individual. Yet, the average individual very often does not exist Molenaar\_2004. To illustrate this problem, let us consider the story of Gilbert Daniels. Daniels was given the task to measure the physical dimensions of more than 4,000 pilots who were part of the American Air Force around 1950. The goal was to find the average pilot size, so that cockpits could be re-designed accordingly. However, a remarkable finding of Daniels was that not a single pilot (out of all pilots who were measured) was approximately equal to the average of the 10 most relevant dimensions. Further, for any given combination of three dimensions, only 4% of pilots would match the average. Hence, he concluded that “The tendency to think in terms of the average man is a pitfall into which many people blunder [...]. Actually, it is virtually impossible to find an average man”. The consequence of this discovery was that most cockpit material became adjustable so that it would suit everyone Rose\_2016.

It is not difficult to translate Daniels’ findings to the field of LA. Here, too, students are measured in many dimensions. It is often implicitly assumed that the average of those dimensions will illustrate “a representative student”, but this is not the case. To accommodate this lack of “average students”, we should embrace person-centered methods, similar to how the American Airforce embraced adjustable furniture and clothing. In contrast to group-level analyses, person-centered methods attempt to find patterns where differences are minimal, assumptions are likely to hold and apply to wider groups of people. Recently, the range of available person-centered methods has vastly increased, coupled with improving rigor and potential. Therefore, person-centered methods are increasingly endorsed to model heterogeneity and individual differences across a vast range of empirical designs. In the current book, we have introduced several methods for capturing the heterogeneity of multivariate and longitudinal data, and we encourage researchers to take advantage of such data to capture the diversity and individual differences of learners Helske\_Helske\_Saqr\_López-Pernas\_Murphy\_2024\_López-Pernas\_Saqr\_2024\_Saqr\_2023b\_Scrucca\_Saqr\_López-Pernas\_Murphy\_2023.

# Conclusion

The birth of learning analytics signaled a new wave of educational research that embraced modern computational methods. Whereas the field has matured, several methodological and theoretical issues remain unresolved. In this chapter, we discussed the potentials of complexity theory and individual differences in advancing the field bringing a much-needed theoretical perspective that could help offer answers to some of our pressing issues. In fact, a complex systems view on learning processes can address some of the major barriers that have hampered progress in the field of education and possibly offer a venue for the renewal of knowledge.

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@article{Hilpert\_Marchand\_2018, title={Complex Systems Research in Educational Psychology: Aligning Theory and Method}, volume={53}, ISSN={0046-1520}, url={http://dx.doi.org/10.1080/00461520.2018.1469411}, DOI={10.1080/00461520.2018.1469411}, abstractNote={The purpose of this work is to provide an overview of complex systems research for educational psychologists. We outline a philosophically and theoretically sourced definition of complex systems research organized around complex, dynamic, and emergent ontological characteristics that is useful and appropriate for educational psychology. A complex systems approach is positioned as a means to align underexplored elements of existing theory with appropriate interaction dominant theoretical models, research methods, and equation-based analytic techniques. We conclude with a brief discussion of several foundational topics for complex systems research in educational psychology.}, number={3}, journal={Educational psychologist}, author={Hilpert, Jonathan C. and Marchand, Gwen C.}, year={2018}, pages={185–202} }

@article{Ifenthaler\_Yau\_2020, title={Utilising learning analytics to support study success in higher education: a systematic review}, ISSN={1042-1629}, url={https://doi.org/10.1007/s11423-020-09788-z}, DOI={10.1007/s11423-020-09788-z}, abstractNote={Study success includes the successful completion of a first degree in higher education to the largest extent, and the successful completion of individual learning tasks to the smallest extent. Factors affecting study success range from individual dispositions (e.g., motivation, prior academic performance) to characteristics of the educational environment (e.g., attendance, active learning, social embeddedness). Recent developments in learning analytics, which are a socio-technical data mining and analytic practice in educational contexts, show promise in enhancing study success in higher education, through the collection and analysis of data from learners, learning processes, and learning environments in order to provide meaningful feedback and scaffolds when needed. This research reports a systematic review focusing on empirical evidence, demonstrating how learning analytics have been successful in facilitating study success in continuation and completion of students’ university courses. Using standardised steps of conducting a systematic review, an initial set of 6220 articles was identified. The final sample includes 46 key publications. The findings obtained in this systematic review suggest that there are a considerable number of learning analytics approaches which utilise effective techniques in supporting study success and students at risk of dropping out. However, rigorous, large-scale evidence of the effectiveness of learning analytics in supporting study success is still lacking. The tested variables, algorithms, and methods collected in this systematic review can be used as a guide in helping researchers and educators to further improve the design and implementation of learning analytics systems.}, number={0123456789}, journal={Educational technology research and development: ETR & D}, publisher={Springer US}, author={Ifenthaler, Dirk and Yau, Jane Yin Kim}, year={2020}, keywords={Attrition; Dropout; Higher education; Learning analytics; Retention; Study success} }

@article{Jörg\_Davis\_Nickmans\_2007, title={Towards a new, complexity science of learning and education}, volume={2}, ISSN={0013-1881}, url={https://dspace.library.uu.nl/bitstream/handle/1874/26124/j\_246\_rg-towards+a+new+complexity+science.pdf?sequence=1}, DOI={10.1016/j.edurev.2007.09.002}, number={2}, journal={Educational research; a review for teachers and all concerned with progress in education}, publisher={Elsevier BV}, author={Jörg, T. and Davis, B. and Nickmans, G.}, year={2007}, month={Jan}, pages={145–156}, language={en} }

@article{Jovanović\_Saqr\_Joksimović\_Gašević\_2021, title={Students matter the most in learning analytics: The effects of internal and instructional conditions in predicting academic success}, volume={172}, ISSN={0360-1315}, url={https://www.sciencedirect.com/science/article/pii/S0360131521001287}, DOI={10.1016/j.compedu.2021.104251}, abstractNote={Predictive modelling of academic success and retention has been a key research theme in Learning Analytics. While the initial work on predictive modelling was focused on the development of general predictive models, portable across different learning settings, later studies demonstrated the drawbacks of not considering the specificities of course design and disciplinary context. This study builds on the methods and findings of related earlier studies to further explore factors predictive of learners’ academic success in blended learning. In doing so, it differentiates itself by (i) relying on a larger and homogeneous course sample (15 courses, 50 course offerings in total), and (ii) considering both internal and external conditions as factors affecting the learning process. We apply mixed effect linear regression models, to examine: i) to what extent indicators of students’ online learning behaviour can explain the variability in the final grades, and ii) to what extent that variability is attributable to the course and students’ internal conditions, not captured by the logged data. Having examined different types of behaviour indicators (e.g., indicators of the overall activity level, those indicative of regularity of study, etc), we found little difference, if any, in their predictive power. Our results further indicate that a low proportion of variance is explained by the behaviour-based indicators, while a significant portion of variability stems from the learners’ internal conditions. Hence, when variability in external conditions is largely controlled for (the same institution, discipline, and nominal pedagogical model), students’ internal state is the key predictor of their course performance.}, journal={Computers & education}, author={Jovanović, Jelena and Saqr, Mohammed and Joksimović, Srećko and Gašević, Dragan}, year={2021}, month={Oct}, pages={104251}, keywords={Data science applications in education; Distance education and online learning} }

@article{Kizilcec\_Reich\_Yeomans\_Dann\_Brunskill\_Lopez\_Turkay\_Williams\_Tingley\_2020, title={Scaling up behavioral science interventions in online education}, volume={117}, url={http://www.pnas.org/content/117/26/14900.abstract}, DOI={10.1073/pnas.1921417117}, abstractNote={Low persistence in educational programs is a major obstacle to social mobility. Scientists have proposed many scalable interventions to support students learning online. In one of the largest international field experiments in education, we iteratively tested established behavioral science interventions and found small benefits depending on individual and contextual characteristics. Forecasting intervention efficacy using state-of-the-art methods yields limited improvements. Online education provides unprecedented access to learning opportunities, as evidenced by its role during the 2020 coronavirus pandemic, but adequately supporting diverse students will require more than a light-touch intervention. Our findings encourage funding agencies and researchers conducting large-scale field trials to consider dynamic investigations to uncover and design for contextual heterogeneity to complement static investigations of overall effects.Online education is rapidly expanding in response to rising demand for higher and continuing education, but many online students struggle to achieve their educational goals. Several behavioral science interventions have shown promise in raising student persistence and completion rates in a handful of courses, but evidence of their effectiveness across diverse educational contexts is limited. In this study, we test a set of established interventions over 2.5 y, with one-quarter million students, from nearly every country, across 247 online courses offered by Harvard, the Massachusetts Institute of Technology, and Stanford. We hypothesized that the interventions would produce medium-to-large effects as in prior studies, but this is not supported by our results. Instead, using an iterative scientific process of cyclically preregistering new hypotheses in between waves of data collection, we identified individual, contextual, and temporal conditions under which the interventions benefit students. Self-regulation interventions raised student engagement in the first few weeks but not final completion rates. Value-relevance interventions raised completion rates in developing countries to close the global achievement gap, but only in courses with a global gap. We found minimal evidence that state-of-the-art machine learning methods can forecast the occurrence of a global gap or learn effective individualized intervention policies. Scaling behavioral science interventions across various online learning contexts can reduce their average effectiveness by an order-of-magnitude. However, iterative scientific investigations can uncover what works where for whom.}, number={26}, journal={Proceedings of the National Academy of Sciences}, author={Kizilcec, René F. and Reich, Justin and Yeomans, Michael and Dann, Christoph and Brunskill, Emma and Lopez, Glenn and Turkay, Selen and Williams, Joseph Jay and Tingley, Dustin}, year={2020}, month={Jun}, pages={14900 LP – 14905} }

@article{Koopmans\_2020, title={Education is a Complex Dynamical System: Challenges for Research}, volume={88}, ISSN={0022-0973}, url={https://doi.org/10.1080/00220973.2019.1566199}, DOI={10.1080/00220973.2019.1566199}, abstractNote={The complex dynamical systems (CDS) approach consists of a family of theories emanating largely from the exact sciences. These theories share a common focus on the behavior of systems and their interrelated parts and are concerned with the processes of stability, change, and unpredictability in those systems. This article takes stock of the methods tailored toward the study of complex dynamical systems in education—for example, the interaction between teachers and students in classrooms, educational organizations such as school buildings and districts, and collaborative learning settings. A historical and conceptual background is provided as a context for CDS. Use of the perspective in education is evaluated according to three basic systemic assumptions: Systems behavior is complex, it evolves over time, and the nature of systemic transformation is qualitative. A comprehensive yet incomplete overview is provided of available research methodologies concerned with those assumptions.}, number={3}, journal={Journal of experimental education}, publisher={Routledge}, author={Koopmans, Matthijs}, year={2020}, pages={358–374}, keywords={Complexity; dynamical systems; educational change; methodology; school reform} }

@article{Ladyman\_Lambert\_Wiesner\_2013, title={What is a complex system?}, volume={3}, ISSN={1879-4912}, url={https://doi.org/10.1007/s13194-012-0056-8}, DOI={10.1007/s13194-012-0056-8}, abstractNote={Complex systems research is becoming ever more important in both the natural and social sciences. It is commonly implied that there is such a thing as a complex system, different examples of which are studied across many disciplines. However, there is no concise definition of a complex system, let alone a definition on which all scientists agree. We review various attempts to characterize a complex system, and consider a core set of features that are widely associated with complex systems in the literature and by those in the field. We argue that some of these features are neither necessary nor sufficient for complexity, and that some of them are too vague or confused to be of any analytical use. In order to bring mathematical rigour to the issue we then review some standard measures of complexity from the scientific literature, and offer a taxonomy for them, before arguing that the one that best captures the qualitative notion of the order produced by complex systems is that of the Statistical Complexity. Finally, we offer our own list of necessary conditions as a characterization of complexity. These conditions are qualitative and may not be jointly sufficient for complexity. We close with some suggestions for future work.}, number={1}, journal={European Journal for Philosophy of Science}, author={Ladyman, James and Lambert, James and Wiesner, Karoline}, year={2013}, month={Jan}, pages={33–67} }

@article{Larrabee Sønderlund\_Hughes\_Smith\_2019, title={The efficacy of learning analytics interventions in higher education: A systematic review}, volume={50}, ISSN={0007-1013}, url={https://onlinelibrary.wiley.com/doi/abs/10.1111/bjet.12720}, DOI={10.1111/bjet.12720}, number={5}, journal={British journal of educational technology: journal of the Council for Educational Technology}, author={Larrabee Sønderlund, Anders and Hughes, Emily and Smith, Joanne}, year={2019}, month={Sep}, pages={2594–2618} }

@inbook{López-Pernas\_Saqr\_2024, title={Modelling the Dynamics of Longitudinal Processes in Education. A tutorial with R for The VaSSTra Method}, booktitle={Learning analytics methods and tutorials: A practical guide using R}, publisher={Springer}, author={López-Pernas, Sonsoles and Saqr, Mohammed}, editor={Saqr, Mohammed and López-Pernas, Sonsoles}, year={2024}, pages={in–press} }

@inbook{Masten\_Nelson\_Gillespie\_2022, address={Cham}, title={Resilience and Student Engagement: Promotive and Protective Processes in Schools}, ISBN={9783031078538}, url={https://doi.org/10.1007/978-3-031-07853-8\_12}, DOI={10.1007/978-3-031-07853-8\_12}, abstractNote={Effective schools buffer students against the effects of adversity on learning and positive adjustment in the present and prepare them for future resilience. This chapter draws on the developmental literature about resilience in children and the educational psychology literature on student engagement to highlight the multifaceted role of schools in resilience. We adopt a scalable and multidisciplinary systems definition of resilience as the capacity of a dynamic system to adapt successfully to challenges that threaten the function, survival, or development of the system. We consider the multifaceted roles in promoting and nurturing resilience of student engagement, broadly defined to include behavioral, emotional, and cognitive processes that connect students to learning and their school communities. Student engagement affords greater access to resources and resilience capacity that can protect children at risk due to acute and chronic adverse childhood experiences while also facilitating the development of resilience factors widely implicated as the building blocks of future competence and resilience. Student engagement processes mediate, moderate, and reflect the processes by which school systems can support and nurture student resilience through multisystem interactions. A “short list” of resilience factors consistently associated with student resilience is delineated along with multiple ways that schools support and nurture these influential factors. Schools can mitigate risk, provide an array of resources and opportunities, and simultaneously nurture powerful adaptive systems that build future resilience for individuals and thereby their communities and societies.}, booktitle={Handbook of Research on Student Engagement}, publisher={Springer International Publishing}, author={Masten, Ann S. and Nelson, Kayla M. and Gillespie, Sarah}, editor={Reschly, Amy L. and Christenson, Sandra L.}, year={2022}, pages={239–255} }

@article{Mennin\_2007, title={Small-group problem-based learning as a complex adaptive system}, volume={23}, ISSN={0742-051X}, url={https://www.sciencedirect.com/science/article/pii/S0742051X06002150}, DOI={10.1016/j.tate.2006.12.016}, abstractNote={Small-group problem-based learning (PBL) is widely embraced as a method of study in health professions schools and at many different levels of education. Complexity science provides a different lens with which to view and understand the application of this method. It presents new concepts and vocabulary that may be unfamiliar to practitioners of small-group PBL and other educational methods. This article looks at small-group PBL from the perspective of complex adaptive systems (CAS). It begins with a brief review of the current understanding and practice of PBL. Next some of the characteristics of CAS are reviewed using examples from small-group PBL to illustrate how these characteristics are expressed in that context. The principles and the educational theory in which small-group PBL are embedded are related to CAS. Implications for health professions education are discussed.}, number={3}, journal={Teaching and Teacher Education}, author={Mennin, Stewart}, year={2007}, month={Apr}, pages={303–313}, keywords={Small groups; Problem-based learning; Complex adaptive systems; Educational theory} }

@article{Molenaar\_2004, title={A Manifesto on Psychology as Idiographic Science: Bringing the Person Back ...: EBSCOhost}, volume={2}, ISSN={1536-6367}, url={https://web-a-ebscohost-com.ep.fjernadgang.kb.dk/ehost/pdfviewer/pdfviewer?vid=1&sid=257bbb8e-f698-4c63-8a11-d87feb3bbf63%40sessionmgr4010}, number={4}, journal={Measurement: interdisciplinary research and perspectives}, author={Molenaar, P. C. M.}, year={2004}, pages={201–218}, keywords={asked what they considered; ergodic-; idiography; interindividual variation; intraindividual variation; ity; most important scientific breakthrough; of disciplines were; of the new millennium; psychological processes; scientists of all kinds; to be the single; when at the start} }

@article{Molenaar\_Campbell\_2009, title={The new person-specific paradigm in psychology}, volume={18}, ISSN={0963-7214}, url={http://dx.doi.org/10.1111/j.1467-8721.2009.01619.x}, DOI={10.1111/j.1467-8721.2009.01619.x}, abstractNote={Most research methodology in the behavioral sciences employs interindividual analyses, which provide information about the state of affairs of the population. However, as shown by classical mathematical-statistical theorems (the ergodic theorems), such analyses do not provide information for, and cannot be applied at, the level of the individual, except on rare occasions when the processes of interest meet certain stringent conditions. When psychological processes violate these conditions, the interindividual analyses that are now standardly applied have to be replaced by analysis of intraindividual variation in order to obtain valid results. Two illustrations involving analysis of intraindividual variation of personality and emotional processes are given. © 2009 Association for Psychological Science.}, number={2}, journal={Current directions in psychological science}, author={Molenaar, Peter C. M. and Campbell, Cynthia G.}, year={2009}, pages={112–117}, keywords={Big Five Personality Factors; Emotional experiences; Ergodic conditions; Interindividual variation; Intraindividual variation; P-technique; R-technique} }

@article{Olthof\_Hasselman\_Aas\_Lamoth\_Scholz\_Daniels-Wredenhagen\_Goldbeck\_Weinans\_Strunk\_Schiepek\_et al.\_2023, title={The best of both worlds? General principles of psychopathology in personalized assessment}, volume={132}, ISSN={2769-755X}, url={http://dx.doi.org/10.1037/abn0000858}, DOI={10.1037/abn0000858}, abstractNote={A complex systems approach to psychopathology proposes that general principles lie in the dynamic patterns of psychopathology, which are not restricted to specific psychological processes like symptoms or affect. Hence, it must be possible to find general change profiles in time series data of fully personalized questionnaires. In the current study, we examined general change profiles in personalized self-ratings and related these to four measures of treatment outcome (International Symptom Rating, 21-item Depression Anxiety and Stress Scale, daily symptom severity, and self-reflective capacity). We analyzed data of 404 patients with mood and/or anxiety disorders who completed daily self-ratings on personalized questionnaires during psychotherapy. For each patient, a principal component analysis was applied to the multivariate time series in order to retrieve an univariate person-specific time series. Then, using classification and regression methods, we examined these time series for the presence of general change profiles. The change profile classification yielded the following distribution of patients: no-shift (n = 55; 14%), gradual-change (n = 52; 13%), one-shift (n = 233; 58%), reversed-shift (n = 39; 10%) and multiple-shifts (n = 25; 6%). The multiple-shift group had better treatment outcome than the no-shift group on all outcome measures. The one-shift and gradual-change groups had better treatment outcome than the no-shift group on two and three outcome measures, respectively. Overall, this study illustrates that person-specific (idiographic) and general (nomothetic) aspects of psychopathology can be integrated in a complex systems approach to psychopathology, which may combine “the best of both worlds.” (PsycInfo Database Record (c) 2023 APA, all rights reserved).}, number={7}, journal={Journal of psychopathology and clinical science}, author={Olthof, Merlijn and Hasselman, Fred and Aas, Benjamin and Lamoth, Daniela and Scholz, Silvia and Daniels-Wredenhagen, Nora and Goldbeck, Florens and Weinans, Els and Strunk, Guido and Schiepek, Günter and Bosman, Anna M. T. and Lichtwarck-Aschoff, Anna}, year={2023}, month={Oct}, pages={808–819}, language={en} }

@article{Olthof\_Hasselman\_Oude Maatman\_Bosman\_Lichtwarck-Aschoff\_2023, title={Complexity theory of psychopathology}, volume={132}, ISSN={2769-755X}, url={http://dx.doi.org/10.1037/abn0000740}, DOI={10.1037/abn0000740}, abstractNote={There is a renewed interest for complex adaptive system approaches that can account for the inherently complex and dynamic nature of psychopathology. Yet a theory of psychopathology grounded in the principles of complex adaptive systems is lacking. Here, we present such a theory based on the notion of dynamic patterns: patterns that are formed over time. We propose that psychopathology can be understood as a dynamic pattern that emerges from self-organized interactions between interdependent biopsychosocial processes in a complex adaptive system comprising a person in their environment. Psychopathology is emergent in the sense that it refers to the person-environment system as a whole and cannot be reduced to specific system parts. Psychopathology as a dynamic pattern is also self-organized, meaning that it arises solely from the interdependencies in the system: the interactions between countless biopsychosocial variables. All possible manifestations of psychopathology will correspond to a wide variety of dynamic patterns. Yet we propose that the development of these patterns over time can be described by general principles of pattern formation in complex adaptive systems. A discussion of implications for classification, intervention, and public health concludes the article. (PsycInfo Database Record (c) 2023 APA, all rights reserved).}, number={3}, journal={Journal of psychopathology and clinical science}, author={Olthof, Merlijn and Hasselman, Fred and Oude Maatman, Freek and Bosman, Anna M. T. and Lichtwarck-Aschoff, Anna}, year={2023}, month={Apr}, pages={314–323}, language={en} }

@article{Panadero\_2017, title={A Review of Self-regulated Learning: Six Models and Four Directions for Research}, volume={8}, ISSN={1664-1078}, url={http://dx.doi.org/10.3389/fpsyg.2017.00422}, DOI={10.3389/fpsyg.2017.00422}, abstractNote={Self-regulated learning (SRL) includes the cognitive, metacognitive, behavioral, motivational, and emotional/affective aspects of learning. It is, therefore, an extraordinary umbrella under which a considerable number of variables that influence learning (e.g., self-efficacy, volition, cognitive strategies) are studied within a comprehensive and holistic approach. For that reason, SRL has become one of the most important areas of research within educational psychology. In this paper, six models of SRL are analyzed and compared; that is, Zimmerman; Boekaerts; Winne and Hadwin; Pintrich; Efklides; and Hadwin, Järvelä and Miller. First, each model is explored in detail in the following aspects: (a) history and development, (b) description of the model (including the model figures), (c) empirical support, and (d) instruments constructed based on the model. Then, the models are compared in a number of aspects: (a) citations, (b) phases and subprocesses, (c) how they conceptualize (meta)cognition, motivation and emotion, (d) top-down/bottom-up, (e) automaticity, and (f) context. In the discussion, the empirical evidence from the existing SRL meta-analyses is examined and implications for education are extracted. Further, four future lines of research are proposed. The review reaches two main conclusions. First, the SRL models form an integrative and coherent framework from which to conduct research and on which students can be taught to be more strategic and successful. Second, based on the available meta-analytic evidence, there are differential effects of SRL models in light of differences in students’ developmental stages or educational levels. Thus, scholars and teachers need to start applying these differential effects of the SRL models and theories to enhance students’ learning and SRL skills.}, journal={Frontiers in psychology}, author={Panadero, Ernesto}, year={2017}, month={Apr}, pages={422}, keywords={emotion regulation; learning strategies; metacognition; motivation regulation; self-regulated learning; self-regulation; shared regulation of learning; socially shared regulated learning}, language={en} }

@article{Papi\_Hiver\_2020, title={Language learning motivation as a complex dynamic system: A global perspective of truth, control, and value}, volume={104}, ISSN={0026-7902}, url={https://onlinelibrary.wiley.com/doi/10.1111/modl.12624}, DOI={10.1111/modl.12624}, abstractNote={Abstract Research on language learning motivation has typically focused on the strength of different motives in isolation and often out of context. The present study aims to explore the applicability of one global framework of motivation to integrate different perspectives. We investigated how adaptive interactions between learners? motivations for value, truth, and control effectiveness, and contextual factors led to varying motivational trajectories and patterns of emergent stability at different stages of the language-learning experiences of 6 Iranian graduate students learning English in the United States. Using a retrospective-longitudinal design, quasi-narrative accounts of key phases of the learners? language-learning histories were documented through interviews. These data were analyzed following an analytic inductive approach to identify the main events within different contexts, themes associated with each setting, and other bottom-up conceptual categories. Using a process-tracing procedure our results showed that dynamic processes and adaptive or competitive interactions between value-, control-, and truth-related motivations and the context in which they emerged resulted in specific motivational trajectories that shaped these learners? language-learning choices and experiences. We discuss the contribution of these novel frameworks for understanding the complex motivational development of language learners.}, number={1}, journal={Modern Language Journal}, publisher={Wiley}, author={Papi, Mostafa and Hiver, Phil}, year={2020}, month={Mar}, pages={209–232}, language={en} }

@article{Paul\_1967, title={Strategy of outcome research in psychotherapy}, volume={31}, ISSN={0095-8891}, url={http://dx.doi.org/10.1037/h0024436}, DOI={10.1037/h0024436}, number={2}, journal={Journal of consulting psychology}, author={Paul, G. L.}, year={1967}, month={Apr}, pages={109–118}, language={en} }

@article{Quintana\_2023, title={Embracing complexity in social science research}, volume={57}, ISSN={0033-5177}, url={https://doi.org/10.1007/s11135-022-01349-1}, DOI={10.1007/s11135-022-01349-1}, abstractNote={Social and behavioral phenomena are fundamentally complex in the sense that they are shaped by many interdependent causes. Researchers that adopt a complex systems perspective have argued that, rather than focusing on a single causal relationship at a time, we need to investigate how the interaction or combination of different factors generate specific outcomes. The main objective of this article is to review three methodological frameworks that have been used to investigate the interdependencies between causal factors, which is often referred to as the study of causal complexity. The three frameworks are: interaction analysis, which investigates effect heterogeneity; structural analysis, which investigates causal mechanisms; and configurational analysis, which investigates sufficient and necessary conditions. I summarize the goals and recent developments of these techniques, as well as two theoretical frameworks—intersectionality theory and the so-called “heterogeneity revolution”—that stress the importance of investigating causal complexity in social science research.}, number={1}, journal={Quality & quantity}, author={Quintana, Rafael}, year={2023}, month={Feb}, pages={15–38} }

@inbook{Reschly\_Christenson\_2022, address={Cham}, title={Jingle-Jangle Revisited: History and Further Evolution of the Student Engagement Construct}, ISBN={9783031078538}, url={https://doi.org/10.1007/978-3-031-07853-8\_1}, DOI={10.1007/978-3-031-07853-8\_1}, abstractNote={This chapter describes the history and evolution of the student engagement construct, with origins in time-on-task, high school dropout, and school reform to its current status as a meta-construct and framework for interventions to promote positive outcomes among youth. We review and compare three integrative models of student engagement: the Check & Connect Model of Student Engagement, the Development-in-Sociocultural-Context Model, and the Study Demands Resources Model of Student Engagement and Burnout. We reflect on the status of prominent issues in the field—jingle-jangle; motivation and engagement; and, the continuum vs. continua of engagement and disengagement/disaffection—and identify enduring themes and directions for the study of student engagement.}, booktitle={Handbook of Research on Student Engagement}, publisher={Springer International Publishing}, author={Reschly, Amy L. and Christenson, Sandra L.}, editor={Reschly, Amy L. and Christenson, Sandra L.}, year={2022}, pages={3–24} }

@book{Rose\_2016, title={The End of Average: How to Succeed in a World That Values Sameness}, ISBN={9780141980027}, url={https://play.google.com/store/books/details?id=w7-zCgAAQBAJ}, abstractNote={“Must the tyranny of the group rule us from cradle to grave? Absolutely not, says Todd Rose in a subversive and readable introduction to what has been called the new science of the individual ... Readers will be moved” Abigail Zuger, The New York Times’Groundbreaking ... The man who can teach you how not to be average’ Anna Hart, Daily Telegraph’Fascinating, engaging, and practical. The End of Average will help everyone - and I mean everyone - live up to their potential’ Amy Cuddy, author of Presence’Lively and entertaining ... a cheering story of how the square pegs among us can build successful lives despite being unable or unwilling to fit into round holes’ Matthew Reisz, Times Higher Education’Heartening . . . a worthwhile read for the aspiring nonconformist’ Iain Morris, Observer}, publisher={Penguin UK}, author={Rose, Todd}, year={2016}, month={Jan}, language={en} }

@article{Saqr\_2023a, title={Modelling within‐person idiographic variance could help explain and individualize learning}, url={http://dx.doi.org/10.1111/bjet.13309}, DOI={10.1111/bjet.13309}, journal={British Journal of Educational Technology}, author={Saqr, Mohammed}, year={2023} }

@article{Saqr\_2023b, title={Group-level analysis of engagement poorly reflects individual students’ processes: Why we need idiographic learning analytics}, ISSN={0747-5632}, url={http://dx.doi.org/10.1016/j.chb.2023.107991}, DOI={10.1016/j.chb.2023.107991}, journal={Computers in human behavior}, author={Saqr, Mohammed}, year={2023} }

@article{Saqr\_Elmoazen\_Tedre\_López-Pernas\_Hirsto\_2022, title={How well centrality measures capture student achievement in computer-supported collaborative learning? – A systematic review and meta-analysis}, volume={35}, ISSN={1747-938X}, url={https://www.sciencedirect.com/science/article/pii/S1747938X22000069}, DOI={10.1016/j.edurev.2022.100437}, abstractNote={Research has shown the value of social collaboration and the benefits it brings to learners. In this study, we investigate the worth of Social Network Analysis (SNA) in translating students’ interactions in computer-supported collaborative learning (CSCL) into proxy indicators of achievement. Previous research has tested the correlation between SNA centrality measures and achievement. Some results indicate a positive association, while others do not. To synthesize research efforts, investigate which measures are of value, and how strong of an association exists, this article presents a systematic review and meta-analysis of 19 studies that included 33 cohorts and 16 centrality measures. Achievement was operationalized in most of the reviewed studies as final course or task grade. All studies reported that one or more centrality measures had a positive and significant correlation with, or a potential for predicting, achievement. Every centrality measure in the reviewed sample has shown a positive correlation with achievement in at least one study. In all the reviewed studies, degree centralities correlated with achievement in terms of final course grades or other achievement measure with the highest magnitude. Eigenvector-based centralities (Eigenvector, PageRank, hub, and authority values) were also positively correlated and mostly statistically significant in all the reviewed studies. These findings emphasize the robustness and reliability of degree- and eigenvector-based centrality measures in understanding students’ interactions in relation to achievement. In contrast, betweenness and closeness centralities have shown mixed or weak correlations with achievement. Taken together, our findings support the use of centrality measures as valid proxy indicators of academic achievement and their utility for monitoring interactions in collaborative learning settings.}, journal={Educational Research Review}, author={Saqr, Mohammed and Elmoazen, Ramy and Tedre, Matti and López-Pernas, Sonsoles and Hirsto, Laura}, year={2022}, month={Feb}, pages={100437}, keywords={Centrality measures; CSCL; Achievement; Social network analysis; Learning analytics; Predicting performance; Educational data mining} }

@article{Saqr\_Jovanovic\_Viberg\_Gašević\_2022, title={Is there order in the mess? A single paper meta-analysis approach to identification of predictors of success in learning analytics}, ISSN={0307-5079}, url={http://dx.doi.org/10.1080/03075079.2022.2061450}, DOI={10.1080/03075079.2022.2061450}, journal={Studies in higher education}, publisher={Informa UK Limited}, author={Saqr, Mohammed and Jovanovic, Jelena and Viberg, Olga and Gašević, Dragan}, year={2022}, month={Apr}, pages={1–22}, language={en} }

@article{Saqr\_Lopez-Pernas\_2021, title={Idiographic learning analytics: A definition and a case study}, url={http://dx.doi.org/10.1109/icalt52272.2021.00056}, DOI={10.1109/icalt52272.2021.00056}, publisher={IEEE}, author={Saqr, Mohammed and Lopez-Pernas, Sonsoles}, year={2021}, pages={163–165}, keywords={-raphical gaussian models; analytics; idiographic learning; learning analytics; network science; psychological} }

@article{Saqr\_López-Pernas\_Jovanović\_Gašević\_2023, title={Intense, turbulent, or wallowing in the mire: A longitudinal study of cross-course online tactics, strategies, and trajectories}, volume={57}, ISSN={1096-7516}, url={https://www.sciencedirect.com/science/article/pii/S1096751622000586}, DOI={10.1016/j.iheduc.2022.100902}, abstractNote={Research has repeatedly demonstrated that students with effective learning strategies are more likely to have better academic achievement. Existing research has mostly focused on a single course or two, while longitudinal studies remain scarce. The present study examines the longitudinal sequence of students’ strategies, their succession, consistency, temporal unfolding, and whether students tend to retain or adapt strategies between courses. We use a large dataset of online traces from 135 students who completed 10 successive courses (i.e., 1350 course enrollments) in a higher education program. The methods used in this study have shown the feasibility of using trace data recorded by learning management systems to unobtrusively trace and model the longitudinal learning strategies across a program. We identified three program-level strategy trajectories: a stable and intense trajectory related to deep learning where students used diverse strategies and scored the highest grades; a fluctuating interactive trajectory, where students focused on course requirements, scored average grades, and were relatively fluctuating; and a light trajectory related to surface learning where students invested the least effort, scored the lowest grades, and had a relatively stable pathway. Students who were intensely active were more likely to transfer the intense strategies and therefore, they were expected to require less support or guidance. Students focusing on course requirements were not as effective self-regulators as they seemed and possibly required early guidance and support from teachers. Students with consistent light strategies or low effort needed proactive guidance and support.}, journal={The Internet and Higher Education}, author={Saqr, Mohammed and López-Pernas, Sonsoles and Jovanović, Jelena and Gašević, Dragan}, year={2023}, month={Apr}, pages={100902}, keywords={Learning analytics; Learning strategies; Sequence analysis; Longitudinal studies} }

@article{Saqr\_Poquet\_López-Pernas\_2022, title={Networks in Education: A Travelogue Through Five Decades}, volume={10}, ISSN={2169-3536}, url={http://dx.doi.org/10.1109/ACCESS.2022.3159674}, DOI={10.1109/ACCESS.2022.3159674}, abstractNote={For over five decades, researchers have used network analysis to understand educational contexts, spanning diverse disciplines and thematic areas. The wealth of traditions and insights accumulated through these interdisciplinary efforts is a challenge to synthesize with a traditional systematic review. To overcome this difficulty in reviewing 1791 articles researching the intersection of networks and education, this study combined a scientometric approach with a more qualitative analysis of metadata, such as keywords and authors. Our analysis shows rapidly growing research that employs network analysis in educational contexts. This research output is produced by researchers in a small number of developed countries. The field has grown more recently, through the surge in the popularity of data-driven methods, the adoption of social media, and themes as teacher professional development and the now-declining MOOC research. Our analysis suggests that research combining networks and educational phenomena continues to lack an academic home, as well as remains dominated by descriptive network methods that depict phenomena such as interpersonal friendship or patterns of discourse-based collaboration. We discuss the gaps in existing research, the methodological shortcomings, the possible future directions and most importantly how network research could help advance our knowledge of learning, learners, and contribute to our knowledge and to learning theories.}, journal={IEEE Access}, author={Saqr, Mohammed and Poquet, Oleksandra and López-Pernas, Sonsoles}, year={2022}, pages={32361–32380}, keywords={Education;Network analyzers;Collaboration;Bibliometrics;Measurement;Market research;Knowledge engineering;Social network analysis;learning analytics;network science;bibliometrics;education} }

@book{Scheffer\_2009, title={Critical Transitions in Nature and Society}, ISBN={9781400833276}, url={https://play.google.com/store/books/details?id=okT\_DwAAQBAJ}, abstractNote={How do we explain the remarkably abrupt changes that sometimes occur in nature and society--and can we predict why and when they happen? This book offers a comprehensive introduction to critical transitions in complex systems--the radical changes that happen at tipping points when thresholds are passed. Marten Scheffer accessibly describes the dynamical systems theory behind critical transitions, covering catastrophe theory, bifurcations, chaos, and more. He gives examples of critical transitions in lakes, oceans, terrestrial ecosystems, climate, evolution, and human societies. And he demonstrates how to deal with these transitions, offering practical guidance on how to predict tipping points, how to prevent “bad” transitions, and how to promote critical transitions that work for us and not against us. Scheffer shows the time is ripe for understanding and managing critical transitions in the vast and complex systems in which we live. This book can also serve as a textbook and includes a detailed appendix with equations.Provides an accessible introduction to dynamical systems theory Covers critical transitions in lakes, oceans, terrestrial ecosystems, the climate, evolution, and human societies Explains how to predict tipping points Offers strategies for preventing “bad” transitions and triggering “good” ones Features an appendix with equations}, publisher={Princeton University Press}, author={Scheffer, Marten}, year={2009}, language={la} }

@article{Scheffer\_Bascompte\_Brock\_Brovkin\_Carpenter\_Dakos\_Held\_van Nes\_Rietkerk\_Sugihara\_2009, title={Early-warning signals for critical transitions}, volume={461}, ISSN={0028-0836}, url={http://dx.doi.org/10.1038/nature08227}, DOI={10.1038/nature08227}, abstractNote={Complex dynamical systems, ranging from ecosystems to financial markets and the climate, can have tipping points at which a sudden shift to a contrasting dynamical regime may occur. Although predicting such critical points before they are reached is extremely difficult, work in different scientific fields is now suggesting the existence of generic early-warning signals that may indicate for a wide class of systems if a critical threshold is approaching.}, number={7260}, journal={Nature}, author={Scheffer, Marten and Bascompte, Jordi and Brock, William A. and Brovkin, Victor and Carpenter, Stephen R. and Dakos, Vasilis and Held, Hermann and van Nes, Egbert H. and Rietkerk, Max and Sugihara, George}, year={2009}, month={Sep}, pages={53–59}, language={en} }

@article{Scheffer\_Carpenter\_Dakos\_van Nes\_2015, title={Generic Indicators of Ecological Resilience: Inferring the Chance of a Critical Transition}, volume={46}, ISSN={1543-592X}, url={https://doi.org/10.1146/annurev-ecolsys-112414-054242}, DOI={10.1146/annurev-ecolsys-112414-054242}, abstractNote={Ecological resilience is the ability of a system to persist in the face of perturbations. Although resilience has been a highly influential concept, its interpretation has remained largely qualitative. Here we describe an emerging family of methods for quantifying resilience on the basis of observations. A first set of methods is based on the phenomenon of critical slowing down, which implies that recovery upon small perturbations becomes slower as a system approaches a tipping point. Such slowing down can be measured experimentally but may also be indirectly inferred from changes in natural fluctuations and spatial patterns. A second group of methods aims to characterize the resilience of alternative states in probabilistic terms based on large numbers of observations as in long time series or satellite images. These generic approaches to measuring resilience complement the system-specific knowledge needed to infer the effects of environmental change on the resilience of complex systems.}, number={1}, journal={Annual review of ecology, evolution, and systematics}, publisher={Annual Reviews}, author={Scheffer, Marten and Carpenter, Stephen R. and Dakos, Vasilis and van Nes, Egbert H.}, year={2015}, month={Dec}, pages={145–167}, annote={doi: 10.1146/annurev-ecolsys-112414-054242} }

@article{Scholz\_Kelso\_Schöner\_1987, title={Nonequilibrium phase transitions in coordinated biological motion: Critical slowing down and switching time}, volume={123}, ISSN={0375-9601}, url={https://www.sciencedirect.com/science/article/pii/0375960187900387}, DOI={10.1016/0375-9601(87)90038-7}, abstractNote={In new experiments on coordinated biological motion we measure relaxation times and switching times as the system evolves from one coordinated state to another at a critical control parameter value. Deviations from the coordinated state are induced by mechanical perturbations and relative phase is used as an order parameter to monitor the dynamics of the collective state. Clear evidence for critical slowing down, a key feature of nonequilibrium phase transitions, is found. The mean and distribution of switching times closely match predictions from a stochastic dynamic theory. Together with earlier results on critical fluctuations these findings strongly favor an interpretation of coordinative change in biological systems as a nonequilibrium phase transition.}, number={8}, journal={Physics letters. A}, author={Scholz, J. P. and Kelso, J. A. S. and Schöner, G.}, year={1987}, month={Aug}, pages={390–394} }

@article{Schreuder\_Groen\_Wigman\_Wichers\_Hartman\_2023, title={Participation and compliance in a 6-month daily diary study among individuals at risk for mental health problems}, volume={35}, ISSN={1040-3590}, url={http://dx.doi.org/10.1037/pas0001197}, DOI={10.1037/pas0001197}, abstractNote={Intensive longitudinal (IL) measurement, which involves prolonged self-monitoring, may have important clinical applications but is also burdening. This raises the question who takes part in and successfully completes IL measurements. This preregistered study investigated which demographic, personality, economic, social, psychological, or physical participant characteristics are associated with participation and compliance in an IL study conducted in young adults at enhanced risk for psychopathology. Dutch young adults enrolled in the clinical cohort of the TRacking Adolescents’ Individual Lives Survey (TRAILS) were invited to a 6-month daily diary study. Participant characteristics came from five earlier TRAILS assessment waves collected from Age 11 onwards. To evaluate participation, we compared diary study participants (N = 134) to nonparticipants (N = 309) and a sex-matched subsample (N = 1926) of individuals from the general population cohort of TRAILS. To evaluate compliance, we analyzed which characteristics were related to the proportion of completed diary entries. We found that participants (23.6 ± 0.7 years old; 57% male) were largely similar to nonparticipants. In addition, compared to the general population, participants reported more negative scores on nearly all characteristics. Internalizing problems predicted higher compliance. Externalizing problems, antisocial behavior, and daily smoking predicted lower compliance. Thus, in at-risk young adults, who scored lower on nearly every positive characteristic and higher on every negative characteristic relative to the general population, participation in a diary study is unbiased. Small biases in compliance occur, of which researchers should be aware. IL measurement is thus suitable in at-risk populations, which is a requirement for its usefulness in clinical practice. (PsycInfo Database Record (c) 2023 APA, all rights reserved).}, number={2}, journal={Psychological assessment}, author={Schreuder, Marieke J. and Groen, Robin N. and Wigman, Johanna T. W. and Wichers, Marieke and Hartman, Catharina A.}, year={2023}, month={Feb}, pages={115–126}, language={en} }

@article{Scollon\_Kim-Prieto\_Diener\_2003, title={Experience Sampling: Promises and Pitfalls, Strengths and Weaknesses}, volume={4}, ISSN={1389-4978}, url={https://doi.org/10.1023/A:1023605205115}, DOI={10.1023/A:1023605205115}, number={1}, journal={Journal of happiness studies}, author={Scollon, Christie N. and Kim-Prieto, Chu and Diener, Ed}, year={2003}, month={Mar}, pages={5–34} }

@unpublished{Scrucca\_Saqr\_López-Pernas\_Murphy\_2023, title={An introduction and tutorial to model-based clustering in education via Gaussian mixture modelling}, url={http://arxiv.org/abs/2306.06219}, abstractNote={Heterogeneity has been a hot topic in recent educational literature. Several calls have been voiced to adopt methods that capture different patterns or subgroups within students behavior or functioning. Assuming that there is an average pattern that represents the entirety of student populations requires the measured construct to have the same causal mechanism, same development pattern, and affect students in exactly the same way. Using a person-centered method (Finite Gaussian mixture model or latent profile analysis), the present tutorial shows how to uncover the heterogeneity within engagement data by identifying three latent or unobserved clusters. This chapter offers an introduction to the model-based clustering that includes the principles of the methods, a guide to choice of number of clusters, evaluation of clustering results and a detailed guide with code and a real-life dataset. The discussion elaborates on the interpretation of the results, the advantages of model-based clustering as well as how it compares with other methods.}, journal={arXiv [stat.ME]}, author={Scrucca, Luca and Saqr, Mohammed and López-Pernas, Sonsoles and Murphy, Keefe}, year={2023}, month={Jun} }

@article{Siemens\_2013, title={Learning Analytics: The Emergence of a Discipline}, volume={57}, ISSN={0002-7642}, url={https://doi.org/10.1177/0002764213498851}, DOI={10.1177/0002764213498851}, abstractNote={Recently, learning analytics (LA) has drawn the attention of academics, researchers, and administrators. This interest is motivated by the need to better understand teaching, learning, ?intelligent content,? and personalization and adaptation. While still in the early stages of research and implementation, several organizations (Society for Learning Analytics Research and the International Educational Data Mining Society) have formed to foster a research community around the role of data analytics in education. This article considers the research fields that have contributed technologies and methodologies to the development of learning analytics, analytics models, the importance of increasing analytics capabilities in organizations, and models for deploying analytics in educational settings. The challenges facing LA as a field are also reviewed, particularly regarding the need to increase the scope of data capture so that the complexity of the learning process can be more accurately reflected in analysis. Privacy and data ownership will become increasingly important for all participants in analytics projects. The current legal system is immature in relation to privacy and ethics concerns in analytics. The article concludes by arguing that LA has sufficiently developed, through conferences, journals, summer institutes, and research labs, to be considered an emerging research field.}, number={10}, journal={The American behavioral scientist}, publisher={SAGE Publications Inc}, author={Siemens, George}, year={2013}, month={Oct}, pages={1380–1400} }

@inbook{Tinto\_2022, address={Cham}, title={Exploring the Character of Student Persistence in Higher Education: The Impact of Perception, Motivation, and Engagement}, ISBN={9783031078538}, url={https://doi.org/10.1007/978-3-031-07853-8\_17}, DOI={10.1007/978-3-031-07853-8\_17}, abstractNote={This chapter begins with an overview of what we know about rates of college persistence and completion in the United States; what they are for different types of students and types of institutions, and how they have changed over the time between two nationally representative surveys of college persistence carried out by the US Department of Education. This chapter then reviews extant models that seek to explain student persistence. It begins with models that take on the perspective of the institution that asks what it has to do to retain its students, then turns to models that take on the perspective of students who ask how they can persist. Taking on that perspective leads to a discussion of the role of student engagement and motivation in persistence and completion and in turn to the way student self-efficacy, sense of belonging, and perceptions of the relevance of their studies impact decisions to persist. This leads to a more detailed analysis of engagement and the impact of its constituent parts in shaping student persistence and completion. This chapter concludes with a discussion of how network analysis can shed light on the impact of micro-engagements with different members of a network on student persistence and completion.}, booktitle={Handbook of Research on Student Engagement}, publisher={Springer International Publishing}, author={Tinto, Vincent}, editor={Reschly, Amy L. and Christenson, Sandra L.}, year={2022}, pages={357–379} }

@article{Urdan\_Kaplan\_2020, title={The origins, evolution, and future directions of achievement goal theory}, volume={61}, ISSN={0361-476X}, url={https://www.sciencedirect.com/science/article/pii/S0361476X20300278}, DOI={10.1016/j.cedpsych.2020.101862}, abstractNote={Quickly after its introduction in the early 1980′s, achievement goal theory blossomed into one of the most popular frameworks in motivation research. Over three plus decades, the theory evolved in a number of ways. Some of these developments brought about much-needed conceptual and methodological clarity; but, they also involved a shift away from questions of complexity and contextualism that marked the earlier research on achievement goals. In this paper, we consider the original focus of achievement goal theory, several ways in which the theory has changed, and what we have learned from intervention research and examinations of achievement goals among diverse populations. The paper concludes with suggestions for future directions in achievement goal research to increase focus on complexity, educational contexts, and issues of ethnic, cultural, and gender diversity.}, journal={Contemporary educational psychology}, author={Urdan, Tim and Kaplan, Avi}, year={2020}, month={Apr}, pages={101862}, keywords={Achievement goal theory; Goals; Motivation; Classroom research} }

@article{Van Orden\_Holden\_Turvey\_2003, title={Self-organization of cognitive performance}, volume={132}, ISSN={0096-3445}, url={http://dx.doi.org/10.1037/0096-3445.132.3.331}, DOI={10.1037/0096-3445.132.3.331}, abstractNote={Background noise is the irregular variation across repeated measurements of human performance. Background noise remains after task and treatment effects are minimized. Background noise refers to intrinsic sources of variability, the intrinsic dynamics of mind and body, and the internal workings of a living being. Two experiments demonstrate 1/f scaling (pink noise) in simple reaction times and speeded word naming times, which round out a catalog of laboratory task demonstrations that background noise is pink noise. Ubiquitous pink noise suggests processes of mind and body that change each other’s dynamics. Such interaction-dominant dynamics are found in systems that self-organize their behavior. Self-organization provides an unconventional perspective on cognition, but this perspective closely parallels a contemporary interdisciplinary view of living systems.}, number={3}, journal={Journal of experimental psychology. General}, author={Van Orden, Guy C. and Holden, John G. and Turvey, Michael T.}, year={2003}, month={Sep}, pages={331–350}, language={en} }

@article{Vollmeyer\_Rheinberg\_1999, title={Motivation and metacognition when learning a complex system}, volume={14}, ISSN={1878-5174}, url={https://doi.org/10.1007/BF03172978}, DOI={10.1007/BF03172978}, abstractNote={Our cognitive-motivational process model (Vollmeyer & Rheinberg, 1998) assumes that motivational factors (i.e., mastery confidence, incompetence fear, interest, and challenge) affect performance via mediators. Previous studies (Vollmeyer, Rollett, & Rheinberg, 1997) found that strategy systematicity and motivational state during learning mediate the impact of initial motivation on the learning of a complex system. Potential mediators could be other cognitive (e.g., hypothesis testing) and metacognitive aspects, in that more motivated learners (high mastery confidence, low incompetence fear, high interest) analyse more deeply. Verbal protocols from 44 students who learnt to control a complex dynamic system were collected. We measured their initial motivation (on the four factors specified), then during learning we assessed their strategy systematicity and motivational state. Additionally, we analysed the verbal protocols to obtain indicators of learners’ cognitive and metacognitive processes. Performance measures were levels of knowledge acquisition and application. The cognitive-motivational process model was replicated. Qualitative cognitive aspects were added as mediators, however, the results for metacognition were problematic, partly because participants gave relatively few clearly expressed metacognitive statements.}, number={4}, journal={European Journal of Psychology of Education}, author={Vollmeyer, Regina and Rheinberg, Falko}, year={1999}, month={Dec}, pages={541–554} }

@article{Wang\_Fredricks\_2014, title={The reciprocal links between school engagement, youth problem behaviors, and school dropout during adolescence}, volume={85}, ISSN={0009-3920}, url={http://dx.doi.org/10.1111/cdev.12138}, DOI={10.1111/cdev.12138}, abstractNote={Drawing on the self-system model, this study conceptualized school engagement as a multidimensional construct, including behavioral, emotional, and cognitive engagement, and examined whether changes in the three types of school engagement related to changes in problem behaviors from 7th through 11th grades (approximately ages 12-17). In addition, a transactional model of reciprocal relations between school engagement and problem behaviors was tested to predict school dropout. Data were collected on 1,272 youth from an ethnically and economically diverse county (58% African American, 36% European American; 51% females). Results indicated that adolescents who had declines in behavioral and emotional engagement with school tended to have increased delinquency and substance use over time. There were bidirectional associations between behavioral and emotional engagement in school and youth problem behaviors over time. Finally, lower behavioral and emotional engagement and greater problem behaviors predicted greater likelihood of dropping out of school.}, number={2}, journal={Child development}, author={Wang, Ming-Te and Fredricks, Jennifer A.}, year={2014}, pages={722–737}, language={en} }

@article{Wichers\_Schreuder\_Goekoop\_Groen\_2019, title={Can we predict the direction of sudden shifts in symptoms? Transdiagnostic implications from a complex systems perspective on psychopathology}, volume={49}, ISSN={0033-2917}, url={http://dx.doi.org/10.1017/S0033291718002064}, DOI={10.1017/S0033291718002064}, abstractNote={Recently, there has been renewed interest in the application of assumptions from complex systems theory in the field of psychopathology. One assumption, with high clinical relevance, is that sudden transitions in symptoms may be anticipated by rising instability in the system, which can be detected with early warning signals (EWS). Empirical studies support the idea that this principle also applies to the field of psychopathology. The current manuscript discusses whether assumptions from complex systems theory can additionally be informative with respect to the specific symptom dimension in which such a transition will occur (e.g. whether a transition towards anxious, depressive or manic symptoms is most likely). From a complex systems perspective, both EWS measured in single symptom dynamics and network symptom dynamics at large are hypothesized to provide clues regarding the direction of the transition. Challenging research designs are needed to provide empirical validation of these hypotheses. These designs should be able to follow sudden transitions “live” using frequent observations of symptoms within individuals and apply a transdiagnostic approach to psychopathology. If the assumptions proposed are supported by empirical studies then this will signify a large improvement in the possibility for personalized estimations of the course of psychiatric symptoms. Such information can be extremely useful for early intervention strategies aimed at preventing specific psychiatric problems.}, number={3}, journal={Psychological medicine}, author={Wichers, Marieke and Schreuder, Marieke J. and Goekoop, Rutger and Groen, Robin N.}, year={2019}, month={Feb}, pages={380–387}, keywords={Complex systems; psychopathology; transdiagnostic approach}, language={en} }

@article{Winne\_2017, title={Leveraging big data to help each learner and accelerate learning science}, volume={119}, ISSN={0040-0475}, url={https://www.tcrecord.org/books/pdf.asp?ContentID=21769}, number={3}, journal={Teachers College record}, author={Winne, Philip}, year={2017}, pages={1–24} }

@article{Winne\_Zhou\_Egan\_2011, title={Designing assessments of self-regulated learning}, url={https://books.google.com/books?hl=en&lr=&id=6wAoDwAAQBAJ&oi=fnd&pg=PA89&dq=Winne+P+H+Zhou+M+Egan+R+(2011)+Designing+assessments+of+self-regulated+learning+Assessment+of+higher+order+thinking+skills+89-118&ots=pciGWFKGp1&sig=B8PuW54kjRFnNI-QVZbCdeDAgeQ}, abstractNote={Assessment has three key features (American Educational Research Association, 1999). First, a systematic method is applied to collect information (data) that an assessor believes can provide grounds for inferences about attributes of people or objects. Usually, methods take form as an instrument, for example: a list of questions, a task with instructions for completing it or a situation in which the person being assessed behaves. Second, assessors follow a protocol to develop inferences based on the data that was gathered. Third, the …}, journal={Assessment of higher order thinking}, publisher={books.google.com}, author={Winne, Philip H. and Zhou, M. and Egan, R.}, year={2011} }

@article{Yuan\_Zhen\_2021, title={Teaching and Researching Motivation}, volume={12}, ISSN={1664-1078}, url={http://dx.doi.org/10.3389/fpsyg.2021.804304}, DOI={10.3389/fpsyg.2021.804304}, journal={Frontiers in psychology}, author={Yuan, Yongkang and Zhen, Hongjie}, year={2021}, month={Dec}, pages={804304}, keywords={language learning (L2) motivation; language teaching; motivation research; students motivation; teacher motivation to work}, language={en} }

@article{Zimmerman\_Risemberg\_1997, title={Becoming a Self-Regulated Writer: A Social Cognitive Perspective}, volume={22}, ISSN={0361-476X}, url={https://www.sciencedirect.com/science/article/pii/S0361476X9790919X}, DOI={10.1006/ceps.1997.0919}, abstractNote={Becoming an adept writer involves more than knowledge of vocabulary and grammar, it depends on high levels of personal regulation because writing activities are usually self-planned, self-initiated, and self-sustained. We present a social cognitive model of writing composed of three fundamental forms of self-regulation: environmental, behavioral, and covert or personal. Each of these triadic forms of self-regulation interact reciprocally via a cyclic feedback loop through which writers self-monitor and self-react to feedback about the effectiveness of specific self-regulatory techniques or processes. Well known writers’ personal descriptions of ten major self-regulatory techniques are recounted, and empirical studies demonstrating the effectiveness of these self-regulatory techniques are discussed. We conclude that writing self-regulation is a complex system of interdependent processes that are closely linked to an underlying sense of self-efficacy, and we discuss implications of the proposed model of self-regulatory processes and self-beliefs for guiding future research and developing innovative writing instruction.}, number={1}, journal={Contemporary educational psychology}, author={Zimmerman, Barry J. and Risemberg, Rafael}, year={1997}, month={Jan}, pages={73–101} }