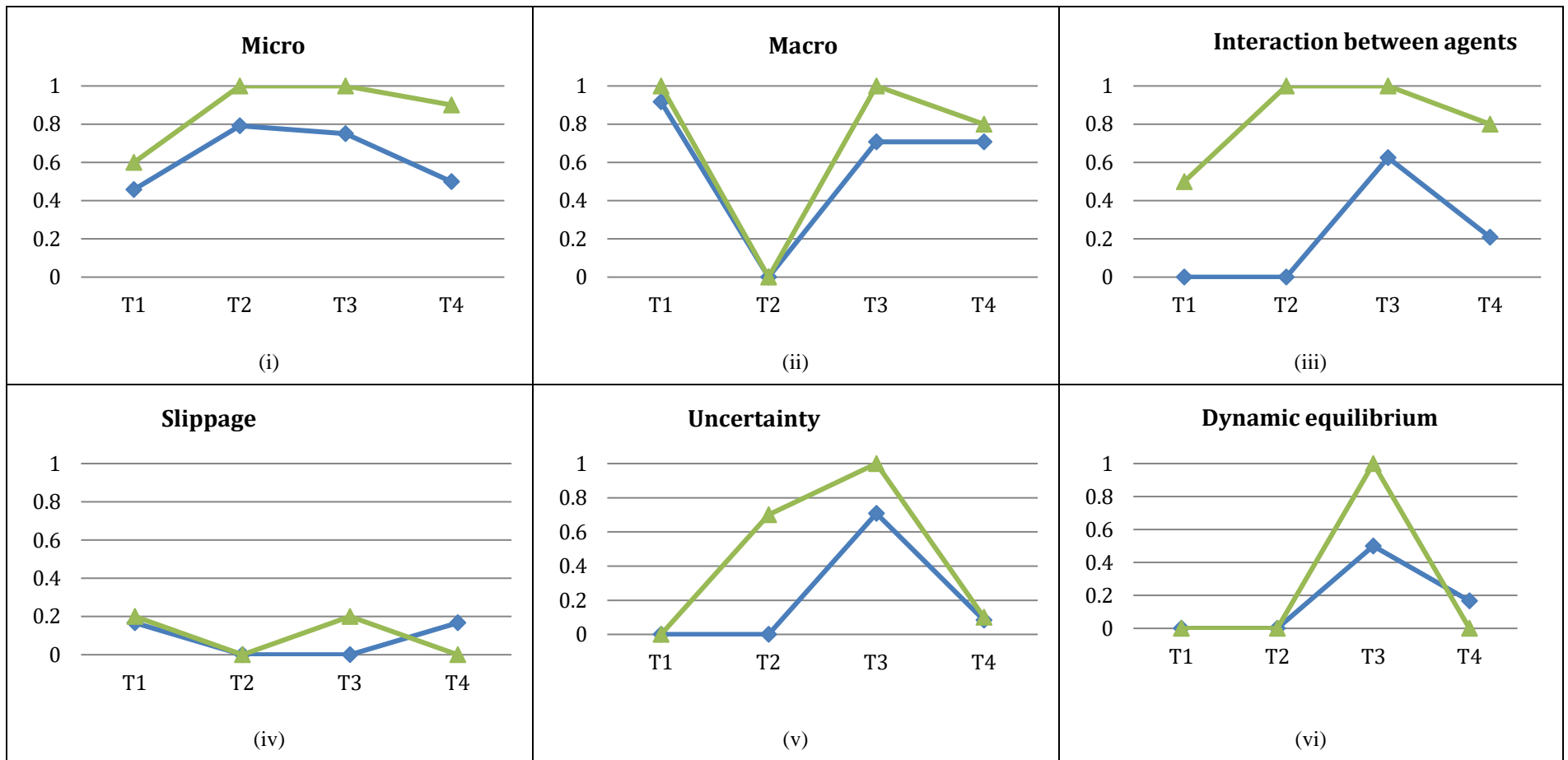


Supplementary Material

Learning progression graphs not included in the main text



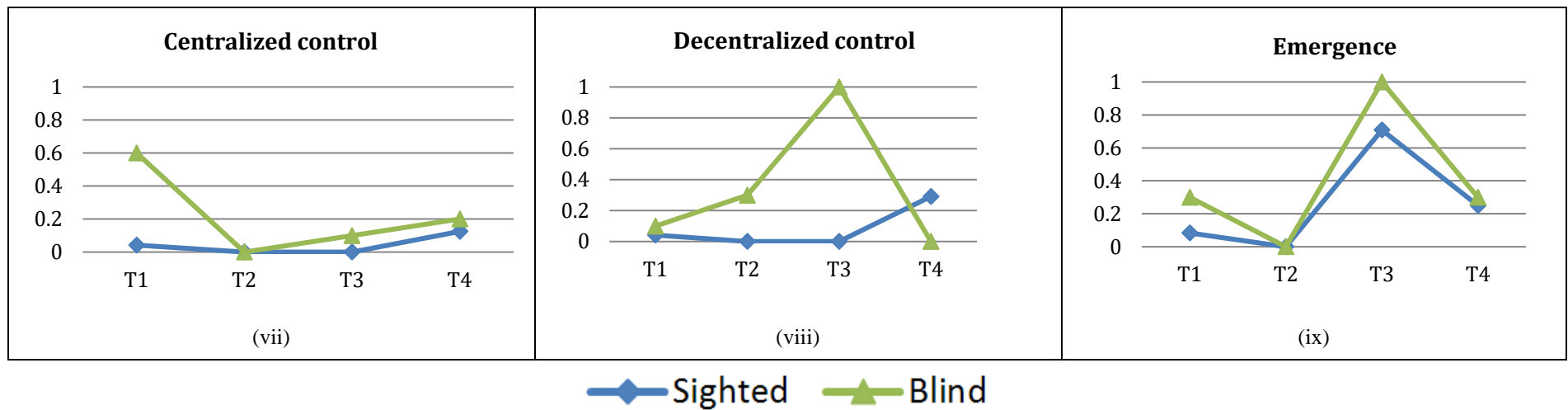
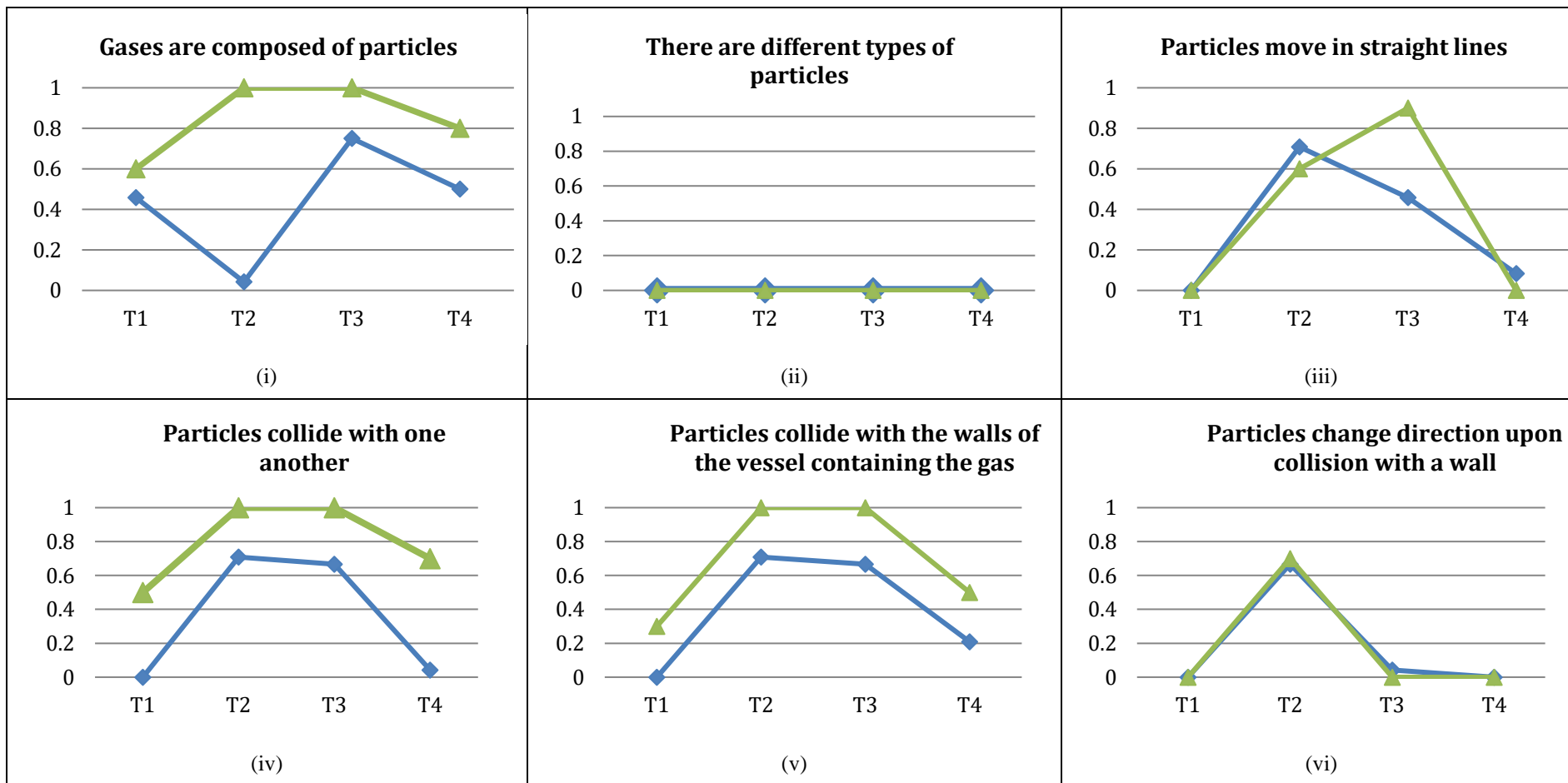
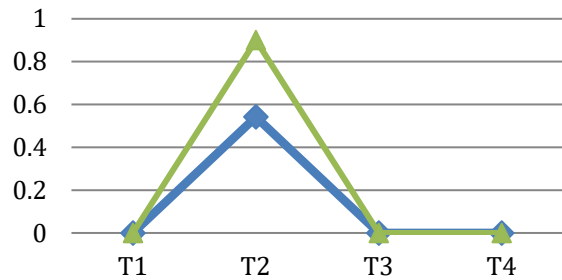


Figure S1. Learning progression of systems thinking.

The graphs depict the expression of nine components of systems thinking in items chosen in four progression analysis windows (T1, T2, T3, T4). The y-axis show the rate of expression of the component in the items. If the component was expressed in all items in the window, the score shown on the graph would be 1.

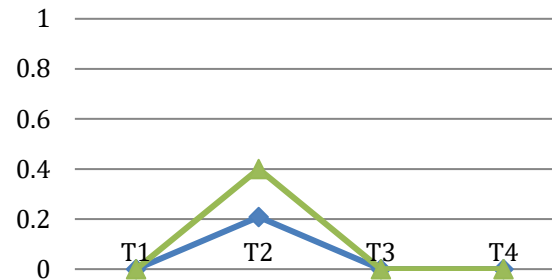


Particles do not change their speed upon collision with a wall



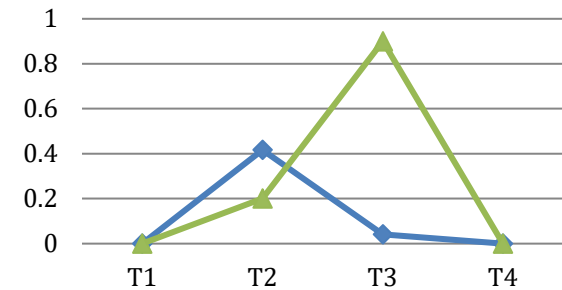
(vii)

Particles change their speed upon collision with a wall (incorrect)



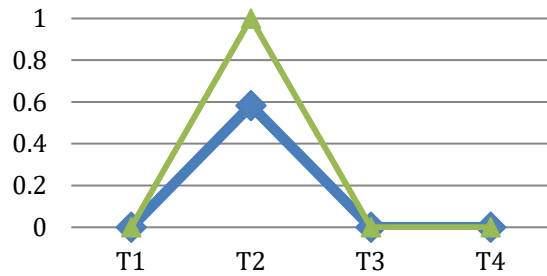
(viii)

Particle change direction upon collision with one another



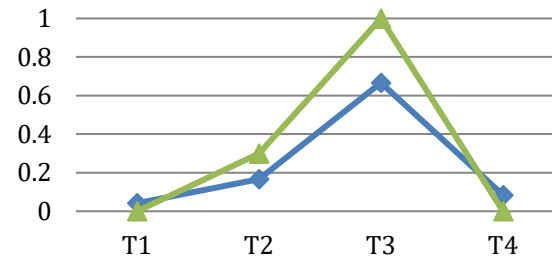
(ix)

Particles change speed upon collision with one another



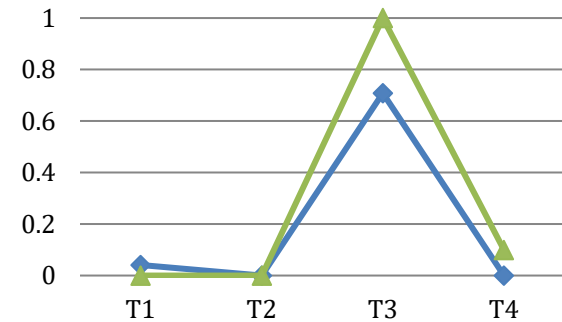
(x)

Particles move in random directions

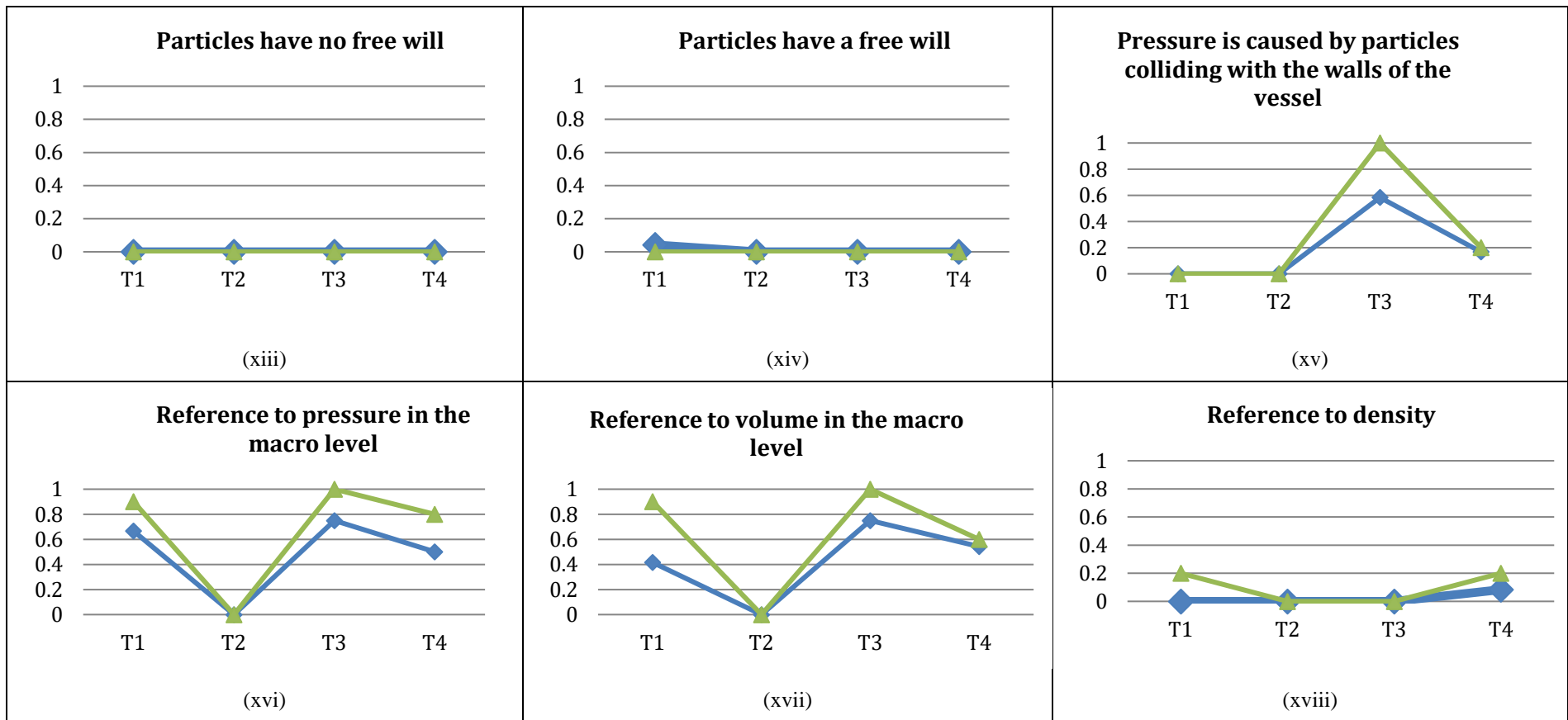


(xi)

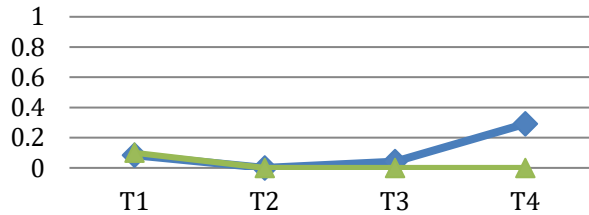
Particles scatter around the room



(xii)

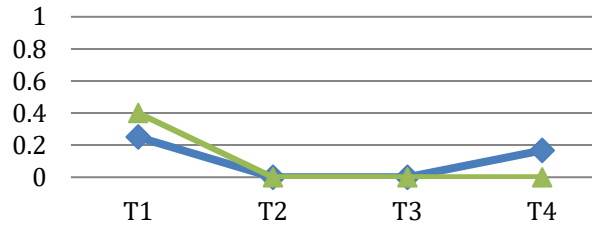


Pressure is effected by the number of particles in the vessel (micro)



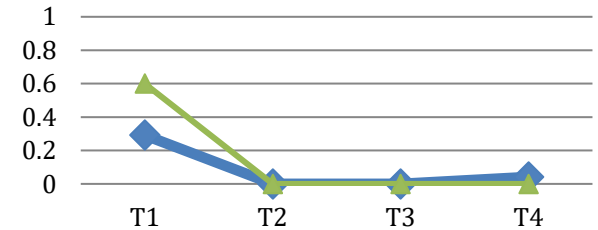
(xix)

Pressure is effected by the quantity of gas in the vessel (macro)



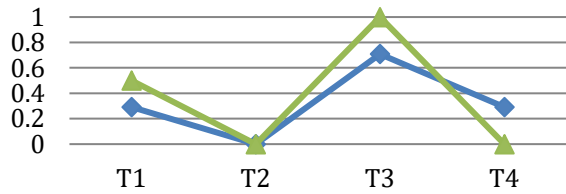
(xx)

Volume is effected by the quantity of gas in the vessel (macro)



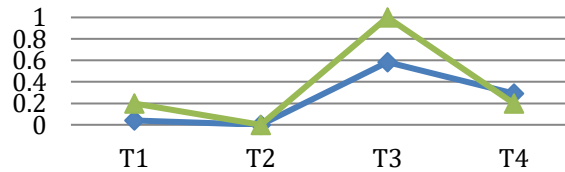
(xxi)

Pressure is effected by changes in the volume of the vessel (macro)



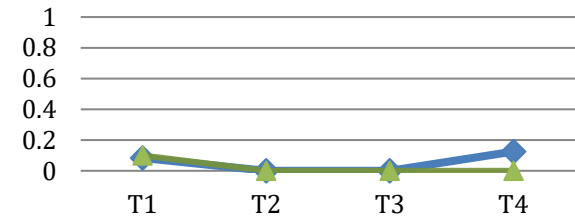
(xxii)

Pressure is effected by changes in the volume of the vessel (micro with reference to particles)



(xxiii)

Pressure changes with the temperature in the vessel



(xxiv)

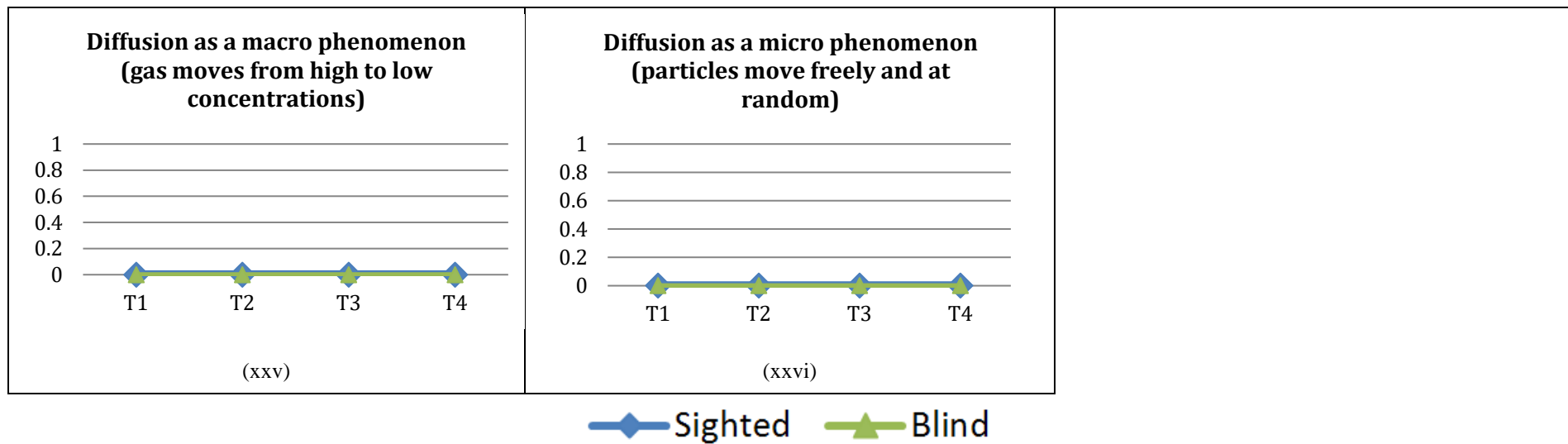


Figure S2. Appearance of 26 specific scientific explanations in the four time windows (T1, T2, T3, T4) in the workbook.

The graphs show expression of specific scientific explanations in four progression analysis windows (T1, T2, T3, T4). The y-axis show the rate of expression of the scientific explanation in the items. If the concept was expressed in all items in the window, the score shown on the graph would be 1.