Supplementary information for

A 4-year longitudinal study investigating the relationship between flexible school starts and grades

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Supplementary Figure S1. Correlations between sleep variables. Spearman rank correlations between the sleep variables social jetlag, chronotype (MSFsc), and sleep duration on schooldays, as well as 9AM-use (frequency of ≥9AM-starts) (n=129). *, p<0.05; **, p<0.01; ***, p<0.001.
Supplementary Table S1. Linear mixed regression models 1 and 2: General and system effects on grades. Predicted outcomes are quarterly grades (0%-100%) in 12 academic subjects from students of cohort 1 and 2 (n=157). Abbreviations: b, unstandardized coefficient; se, standard error; beta, standardized coefficient; t, t-statistic; p, p-value; σ², variance of residuals of random effects; τ₀₀, variance of ID intercepts of random effects; ICC, intra-class correlation coefficient (describes how much variance is explained by the random effects); N, number of participants; Marginal R² describes the amount of variance explained by the fixed effects (predictors); Conditional R² describes the amount of variance explained by the full model.

| Predictors                              | b   | se  | beta | t     | p     | Model 1 | b   | se  | beta | t     | p     | Model 2 |
|-----------------------------------------|-----|-----|------|-------|-------|---------|-----|-----|------|-------|-------|---------|
| (Intercept)                             | 54.11 | 1.21 | 44.74  | <0.001 | 52.79 | 1.21 | 43.56 | <0.001 |
| System: Flexible system**               | -0.10 | 0.42 | -0.00  | -0.23  | 0.815 | 0.64 | 0.55 | 0.02  | 1.16  | 0.244 |
| Gender: Male*                          | -4.72 | 2.13 | -0.12  | -2.21  | 0.028 | -1.43 | 2.12 | -0.03 | -0.67 | 0.501 |
| Grade level: 7**                        | 1.17 | 0.74 | 0.02   | 1.60   | 0.111 | 1.23 | 0.74 | 0.01  | 1.66  | 0.097 |
| Grade level: 8**                        | 3.11 | 0.49 | 0.05   | 6.39   | <0.001 | 3.15 | 0.49 | 0.05  | 6.44  | <0.001 |
| Grade level: 9**                        | 2.59 | 0.34 | 0.06   | 7.53   | <0.001 | 2.62 | 0.35 | 0.06  | 7.58  | <0.001 |
| Grade level: 10**                       | 0.50 | 0.35 | 0.01   | 1.42   | 0.155 | 0.48 | 0.36 | 0.01  | 1.34  | 0.180 |
| Grade level: 11**                       | 3.44 | 0.55 | 0.05   | 6.21   | <0.001 | 3.37 | 0.56 | 0.05  | 6.05  | <0.001 |
| Quarter: 2**                            | 0.82 | 0.32 | 0.02   | 2.59   | 0.010 | 0.82 | 0.32 | 0.02  | 2.58  | 0.010 |
| Quarter: 3**                            | 0.30 | 0.34 | 0.01   | 0.88   | 0.378 | 0.25 | 0.34 | 0.01  | 0.75  | 0.451 |
| Quarter: 4**                            | 2.34 | 0.33 | 0.05   | 7.15   | <0.001 | 2.30 | 0.33 | 0.05  | 7.00  | <0.001 |
| Discipline: Sciences*                   | 3.40 | 0.30 | 0.09   | 11.36  | <0.001 | 5.22 | 0.30 | 0.14  | 17.30 | <0.001 |
| Discipline: Social Sciences*            | 3.87 | 0.36 | 0.08   | 10.69  | <0.001 | 7.25 | 0.37 | 0.16  | 19.33 | <0.001 |
| Male*Sciences                           | 4.74 | 0.54 | 0.08   | 8.83   | <0.001 |       |       |       |       |       |
| Male*Social Sciences                    | 8.03 | 0.65 | 0.11   | 12.44  | <0.001 |       |       |       |       |       |
| Flexible system*Sciences                | -1.23 | 0.54 | -0.02  | -2.29  | 0.022 |       |       |       |       |       |
| Flexible system*Social Sciences         | -2.56 | 0.63 | -0.04  | -4.05  | <0.001 |       |       |       |       |       |
| Flexible system*Male                    | 1.32 | 0.52 | 0.02   | 2.53   | 0.011 |       |       |       |       |       |

| Random Effects                          |     |     |     |      |      | Model 1 |     |     |     |      |      | Model 2 |     |     |     |      |      |
|-----------------------------------------|-----|-----|-----|------|------|---------|-----|-----|-----|------|------|---------|-----|-----|-----|------|------|
| σ²                                      | 200.29 |     |     |      |      | 202.07  |     |     |     |      |      |         |     |     |     |      |      |
| τ₀₀                                     | 146.38 ID | 146.38 ID |     |      |      |         |     |     |     |      |      |         |     |     |     |      |      |
| ICC                                     | 0.42 |     |     |      |      | 0.42    |     |     |     |      |      |         |     |     |     |      |      |
| N                                       | 157 ID |     |     |      |      | 157 ID  |     |     |     |      |      |         |     |     |     |      |      |
| Observations                            | 16724 |     |     |      |      | 16724   |     |     |     |      |      |         |     |     |     |      |      |
| Marginal R² / Conditional R²            | 0.033 / 0.441 | 0.028 / 0.436 |     |      |      |         |     |     |     |      |      |         |     |     |     |      |      |

**Reference is conventional system.
*Reference is female.
**Reference is grade level 10.
***Reference is quarter 1.
****Reference is Languages.
Supplementary Table S2. Post hoc results of mixed models 1 and 2. Results are presented as marginal estimated means of quarterly grades scaled 0-100% (standard error), degrees of freedom. Simple contrast results are presented as estimated difference of academic grades (standard error), p-value. Degrees of freedom method: Kenward-Rogers. Results are averaged over the levels of system or gender, grade level, and quarter. Tukey method for comparison of 3 estimates.

| Model 1 |         |         |         |         |
|---------|---------|---------|---------|---------|
|         | Gender  | Languages | Sciences | Social Sciences | Simple contrasts |
|         |         |         |         |         |         |
|         | female  |         |         |         |         |
|         |         | 56.7 (1.19) | 60.1 (1.19) | 60.6 (1.21) |         |
|         |         | 166 | 166 | 176 |         |
|         | Languages-Sciences: | -3.41 (0.30), p<.0001 | Languages-Social Sciences: | -3.87 (0.36), p<.0001 |
|         |         | Languages-Social Sciences: | -0.47 (0.36), p=0.3895 |         |
|         |         | Languages-Sciences: | -3.76 (0.52), p<.0001 |         |
|         | male    |         |         |         |         |
|         |         | 52.0 (1.79) | 60.2 (1.78) | 63.9 (1.80) |         |
|         |         | 164 | 163 | 172 |         |
|         | Languages-Sciences: | -8.15 (0.45), p=0.0001 | Languages-Social Sciences: | -11.90 (0.54), p<0.0001 |
|         |         | Languages-Social Sciences: | -0.20 (0.37), p=0.0001 |         |
|         |         | Languages-Sciences: | -3.76 (0.52), p<.0001 |         |
|         | Simple contrasts | 4.72 (2.13) | -0.00 (2.13) | -3.31 (2.16) |         |
|         |         | p=0.0284 | p=0.9915 | p=0.1269 |         |
|         | Model 2 |         |         |         |         |
|         |         |         |         |         |         |
|         | System  | Languages | Sciences | Social Sciences | Simple contrasts |
|         |         |         |         |         |         |
|         | conventional | 54.7 (1.08) | 59.9 (1.08) | 62.0 (1.10) |         |
|         |         | 168 | 167 | 182 |         |
|         | Languages-Sciences: | -5.22 (0.30), p=0.0001 | Languages-Social Sciences: | -7.25 (0.38), p=0.0001 |
|         |         | Languages-Social Sciences: | -2.03 (0.37), p=0.0001 |         |
|         |         | Languages-Sciences: | -3.99 (0.45), p<.0001 |         |
|         |         | Languages-Social Sciences: | -4.69 (0.51), p<.0001 |         |
|         |         | Languages-Social Sciences: | -0.69 (0.49), p=0.3355 |         |
|         | flexible |         |         |         |         |
|         |         | 56.0 (1.14) | 60.0 (1.13) | 60.7 (1.16) |         |
|         |         | 212 | 206 | 227 |         |
|         | Languages-Sciences: | -1.30 (0.54), p=0.0168 | Languages-Social Sciences: | -0.07 (0.61), p=0.8849 |
|         |         | Languages-Social Sciences: | 1.26 (0.61), p=0.0384 |         |
|         | Simple contrasts |         |         |         |         |
|         |         |         |         |         |         |
|         | System  | Female | Male |         | Simple contrasts |
|         |         |         |         |         |         |
|         | conventional | 59.6 (1.18) | 58.2 (1.77) |         | female-male: |
|         |         | 160 | 158 |         | 1.43 (2.12), p=0.5010 |
|         |         |         |         |         |         |
|         | flexible | 59.0 (1.22) | 58.9 (1.81) |         | female-male: |
|         |         | 186 | 173 |         | 0.11 (2.14), p=0.9580 |
|         | Simple contrasts | 0.62 (0.45) | 0.7 (0.56) |         |         |
|         |         | p=0.1726 | p=0.2106 |         |         |
Supplementary Table S3. Linear mixed regression models 3a-d: Effect of changes in sleep and of ≥9AM-use on grade improvements from the conventional to the flexible system. Predicted outcomes are quarterly grades (0%-100%) in 12 academic subjects from students of cohort 1 (n=63) over 4 years. “Change” refers to the absolute difference of the respective sleep variable between the conventional and the flexible system (t1-t0). Positive numbers mean later chronotype, longer sleep and more social jetlag in the flexible system (t1). 9AM-use is the frequency of ≥9AM-starts at t1 (no baseline data for calculation of change available). Abbreviations: Flex, Flexible system; b, unstandardized coefficient; se, standard error; beta, standardized coefficient; p, p value; $\sigma^2$, variance of residuals of random effects; $\tau_0$, variance of ID intercepts of random effects; ICC, intra-class correlation coefficient (describes how much variance is explained by the random effects); N, number of participants; Marginal $R^2$ describes the amount of variance explained by the fixed effects (predictors); Conditional $R^2$ describes the amount of variance explained by the full model.

| Predictors | Model3a: Change in Chronotype | Model3b: Change in Sleep duration | Model3c: Change in Social jetlag | Model3d: Change in 9AM-use |
|------------|--------------------------------|----------------------------------|--------------------------------|---------------------------|
| (Intercept) | 53.26 1.97 $<0.001$ | 53.30 1.94 $<0.001$ | 53.29 1.96 $<0.001$ | 53.35 1.86 $<0.001$ |
| System: Flexible system | -0.01 0.68 0.00 0.983 | 0.00 0.68 0.00 0.998 | 0.04 0.68 0.00 0.953 | 0.02 0.68 0.00 0.977 |
| Gender: Male* | -2.56 3.24 -0.07 0.432 | -2.64 3.11 -0.07 0.399 | -2.64 3.15 -0.07 0.405 | -2.80 2.98 -0.07 0.352 |
| Grade level: 7th | 5.96 3.33 0.02 0.074 | 63.31 3.35 0.02 0.060 | 6.46 3.34 0.02 0.053 | 5.89 3.33 0.02 0.077 |
| Grade level: 8th | 2.52 0.77 0.04 0.001 | 2.49 0.77 0.04 0.001 | 2.49 0.77 0.04 0.001 | 2.50 0.76 0.04 0.001 |
| Grade level: 9th | 2.14 0.57 0.05 0.001 | 2.13 0.57 0.05 0.001 | 2.11 0.57 0.05 0.001 | 2.08 0.57 0.05 0.001 |
| Grade level: 11th | 1.07 0.53 0.03 0.045 | 1.08 0.53 0.03 0.042 | 1.11 0.53 0.03 0.039 | 1.11 0.53 0.03 0.038 |
| Grade level: 10th | 3.42 0.82 0.06 0.001 | 3.38 0.82 0.06 0.001 | 3.37 0.82 0.06 0.001 | 3.46 0.82 0.06 0.001 |
| Quarter: 2nd | 0.71 0.50 0.02 0.157 | 0.70 0.50 0.02 0.160 | 0.71 0.50 0.02 0.155 | 0.71 0.50 0.02 0.154 |
| Quarter: 3rd | 0.47 0.54 0.01 0.386 | 0.46 0.54 0.01 0.392 | 0.47 0.54 0.01 0.380 | 0.48 0.54 0.01 0.367 |
| Quarter: 4th | 2.31 0.52 0.05 0.001 | 2.30 0.52 0.05 0.001 | 2.30 0.52 0.05 0.001 | 2.31 0.52 0.05 0.001 |
| Discipline: Sciences* | 6.22 0.40 0.16 0.001 | 6.22 0.40 0.16 0.001 | 6.22 0.40 0.16 0.001 | 6.22 0.40 0.16 0.001 |
| Discipline: Social Sciences* | 7.63 0.48 0.17 <0.001 | 7.63 0.48 0.17 <0.001 | 7.64 0.48 0.17 <0.001 | 7.64 0.48 0.17 <0.001 |
| Chronotype change (MSF_w, h) | 0.40 0.02 0.055 | 0.19 0.00 0.958 | 1.86 0.36 0.03 0.027 |
| Flex* Chronotype change | 0.10 0.53 0.00 0.845 | 2.32 0.94 0.06 0.434 | 0.11 2.11 0.00 0.056 | -3.04 1.21 -0.19 0.015 |
| Sleep duration change (h) | -0.77 0.83 -0.01 0.352 | -0.77 0.83 -0.01 0.352 | 1.28 0.58 0.03 0.027 | -0.59 0.36 0.02 0.101 |
| Social jetlag change (h) | | | | |
| Flex* Social jetlag change | | | | |
| 9AM-use (schooldays/week) | | | | |
| Flex*9AM-use | | | | |
| Random effects | | | | |
| $\sigma^2$ | 205.07 | 205.05 | 204.92 | 204.99 |
| $\tau_0$ | 140.27* | 138.10** | 140.24* | 128.08** |
| ICC | 0.41 | 0.40 | 0.41 | 0.28 |
| N | 63 | 63 | 63 | 63 |
| Observations | 6683 | 6683 | 6683 | 6683 |
| Marginal $R^2$ | 0.040 / 0.430 | 0.043 / 0.430 | 0.041 / 0.430 | 0.071 / 0.428 |
| Conditional $R^2$ | | | | |

*Reference is female.
*Reference is grade level 10.
*Reference is quarter 1.
*Reference is Languages.
### Supplementary Table S4. Linear mixed regression models 4a-e: Effect of absolute sleep characteristics in the flexible system on grades.

Predicted outcomes are quarterly grades (0%-100%) in 12 academic subjects from students of cohorts 1 and 2 (n=129) over 1.5 years in the flexible system. 9AM-use is the frequency of ≥9AM-starts in the flexible system. Abbreviations: b, unstandardized coefficient; se, standard error; beta, standardized coefficient; p, p value; $\sigma^2$, variance of residuals of random effects; $\tau_{00}$, variance of ID intercepts of random effects; ICC, intra-class correlation coefficient (describes how much variance is explained by the random effects); N, number of participants; Marginal R² describes the amount of variance explained by the fixed effects (predictors); Conditional R² describes the amount of variance explained by the full model.

| Predictors | Model 4a: Chronotype | Model 4b: Sleep duration | Model 4c: Social jetlag | Model 4d: 9AM-use | Model 4e: All |
|------------|----------------------|--------------------------|-------------------------|------------------|--------------|
| (Intercept) | b 59.50 | 5.81 | <0.001 | b 65.13 | 10.70 | <0.001 | b 53.68 | 3.40 | <0.001 | b 60.50 | 2.19 | <0.001 | b 64.77 | 14.51 | <0.001 |
| Gender: Male | b -0.31 | 2.61 | -0.01 | b -0.61 | 2.54 | -0.01 | b -0.83 | 2.54 | -0.02 | b -0.72 | 2.49 | -0.02 | b -0.15 | 2.63 | 0.00 | 0.956 |
| Grade level: 9th | b 3.35 | 0.82 | 0.05 | b 3.35 | 0.82 | 0.05 | b 3.36 | 0.82 | 0.05 | b 3.27 | 0.82 | 0.05 | b 3.27 | 0.82 | 0.05 | <0.001 |
| Grade level: 11th | b 0.47 | 0.62 | 0.01 | b 0.46 | 0.62 | 0.01 | b 0.45 | 0.62 | 0.01 | b 0.58 | 0.62 | 0.01 | b 0.57 | 0.62 | 0.01 | 0.355 |
| Grade level: 12th | b 0.02 | 1.00 | 0.00 | b 0.84 | 0.02 | 0.99 | 0.00 | b 0.84 | 0.02 | 0.99 | b 0.83 | 0.02 | 0.99 | 0.00 | b 0.83 | 0.02 | 0.99 | 0.00 |
| Quarter: 2 | b 0.38 | 0.65 | 0.01 | b 0.38 | 0.65 | 0.01 | b 0.38 | 0.65 | 0.01 | b 0.38 | 0.65 | 0.01 | b 0.38 | 0.65 | 0.01 | 0.561 |
| Quarter: 3 | b -0.05 | 0.65 | -0.00 | b -0.06 | 0.65 | -0.00 | b -0.07 | 0.65 | -0.00 | b 0.02 | 0.65 | 0.00 | b 0.02 | 0.65 | 0.00 | 0.979 |
| Quarter: 4 | b 1.69 | 0.61 | 0.04 | b 1.69 | 0.61 | 0.04 | b 1.68 | 0.61 | 0.04 | b 1.76 | 0.61 | 0.05 | b 1.76 | 0.61 | 0.05 | 0.004 |
| Discipline: Sciences | b 4.27 | 0.43 | 0.11 | b 4.28 | 0.43 | 0.11 | b 4.27 | 0.43 | 0.11 | b 4.27 | 0.43 | 0.11 | b 4.28 | 0.43 | 0.11 | <0.001 |
| Discipline: Social Sciences | b 4.65 | 0.49 | 0.10 | b 4.65 | 0.49 | 0.10 | b 4.65 | 0.49 | 0.10 | b 4.65 | 0.49 | 0.10 | b 4.65 | 0.49 | 0.10 | <0.001 |
| Chronotype (local time in h) | b -0.53 | 1.23 | -0.03 | b -1.12 | 1.47 | -0.05 | b 1.76 | 1.54 | 0.07 | b 0.256 | -2.12 | 0.91 | 0.022 | -1.32 | 1.20 | -0.08 | 0.272 |
| Sleep duration (h) | b -2.37 | 2.35 | -0.12 | b 0.315 |
| Social jetlag (h) | b -0.27 | 1.61 | -0.01 | b 0.865 |
| ≥9AM-use (schooldays/week) | b 3.70 | 2.78 | 0.14 | b 0.186 |

#### Random Effects

| | Model 4a | Model 4b | Model 4c | Model 4d | Model 4e |
|----------------|---------|---------|---------|---------|---------|
| $\sigma^2$ | 168.88 | 168.87 | 168.87 | 168.87 | 168.87 |
| $\tau_{00}$ | 174.27 | 173.89 | 172.93 | 167.17 | 168.81 |
| ICC | 0.51 | 0.51 | 0.51 | 0.50 | 0.50 |
| N | 129 | 129 | 129 | 129 | 129 |

| Observations | 5111 | 5111 | 5111 | 5111 | 5111 |
| Marginal R² / Conditional R² | 0.018 / 0.517 | 0.019 / 0.517 | 0.022 / 0.517 | 0.037 / 0.516 | 0.042 / 0.521 |

*aReference is female.
*bReference is grade level 10.
*cReference is quarter 1.
*dReference is Languages.