Research

Seeds of change: reversing the erosion of traditional agroecological knowledge through a citizen science school program in Catalonia, Spain

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ABSTRACT. Understanding valuation of and access to traditional agroecological knowledge (TAeK) in industrialized countries is key to designing initiatives that can reverse the erosion of TAeK. We explored these issues using a quasi-experimental design. We measured valuation and access to TAeK with a survey before and after an intervention based on a citizen science school program. The participants were Catalan agricultural technical students ($N = 173$), i.e., rural youth with an interest in agriculture and natural resources. We found that the study population values TAeK quite highly and accesses it relatively frequently outside the classroom. Moreover, the intervention, together with hands-on activities such as home gardening, had a positive effect on how much and how often students valued and accessed TAeK. Education programs such as the one presented here could become allies in agroecological transitions that require TAeK to be accessible and valued by future farmers.

Key Words: *agroecology; citizen science; contextualized schooling; environmental education; knowledge transmission; traditional agroecological knowledge*

INTRODUCTION

Traditional agroecological knowledge (TAeK) systems, understood as the set of knowledge, practices, and beliefs related to the use and management of the elements in an agroecosystem, are basic components of the world's biocultural heritage (Berkes et al. 2000, Calvet-Mir et al. 2018). Maintaining traditional knowledge systems has been an emerging priority because of their multiple social, ecological, and economic values and their potential relevance for agroecological transitions (Reyes-García 2015, Calvet-Mir et al. 2018). However, despite TAeK's dynamic and adaptive nature that allows its coexistence with other types of knowledge systems, there is a growing consensus among scientists and policy makers regarding its rapid erosion (Reyes-García et al. 2010, 2014, Shukla et al. 2017). Two main factors significantly contribute to traditional knowledge erosion in industrialized societies: its devaluation and its lack of transmission to younger generations (Gómez-Baggethun et al. 2010, Oteros-Rozas et al. 2013, Hernández-Morcillo et al. 2014, Iniesta-Arandia et al. 2015).

First, traditional agroecological practices in Europe have been widely abandoned, partly because of a negative valuation of TAeK systems. This valuation can be understood as the result of a set of socio-cultural, political, and economic factors that influence people's preferences and value perceptions. For instance, agriculture modernization paradigms have resulted in nonindustrial agricultural systems based on TAeK being considered outdated, inefficient, and unworthy (Naredo 2004, Gómez-Baggethun et al. 2010, Hernández-Morcillo et al. 2014). Also, the stigmatization of wild plant consumption, considered a sign of poverty in some contexts, has resulted in the erosion of wild edible plant knowledge (Cruz García 2006, Reyes-García et al. 2015). Finally, acculturation through decontextualized schooling may have also negatively affected TAeK valuation (Castagno and McKinley Jones Brayboy 2008, McCarter et al. 2014). All of these issues are framed by asymmetrical power relations that go back to colonial ideas about the underdevelopment of indigenous and local communities and that favor "expert" over "lay" knowledge (Agrawal 1995, Nadasdy 1999, Burke and Heynen 2014, Benyei et al. 2017).

Second, the lack of traditional knowledge transmission can lead to both knowledge loss and a decline in local communities' capacities to manage natural resources (Fernández-Llamazares et al. 2015, Ianni et al. 2015, Ramet et al. 2018). Traditional knowledge is accessed through a combination of different pathways that include knowledge transmission from peers (horizontal), parents (vertical), and other adults (oblique transmission; Cavalli-Sforza and Feldman 1981, Calvet-Mir et al. 2016). The relevance of these different pathways depends not only on the cultural group, but also on the age and characteristics of the learner (Reyes-García et al. 2016). In this sense, contextualized and intergenerational school activities could result in both horizontal knowledge transmission through fellow students and vertical or oblique knowledge transmission through interactions with elders. Additionally, these activities can increase access to TAeK and help prevent the "biocultural amnesia" (Toledo and Barrera-Bassols 2008) of younger generations (McCarter and Gavin 2014, Tang and Gavin 2016).

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The general decline in TAeK has called the attention of researchers and policy makers, who have started to investigate and promote initiatives to stop the devaluation and enhance the transmission of TAeK (Tang and Gavin 2016, Benyei et al. 2020). An innovative experience in this line has been the development of citizen science school programs focused on documenting TAeK through student-led interviews, which enhance access to TAeK and contribute to counteracting social stigma and to revaluing the community's biocultural patrimony (Sieber and Strohmeier 2016, Calvet-Mir et al. 2018). Citizen science (CS) is a rapidly growing approach referring to the participation of nonprofessional scientists in scientific activities, from research design to data collection and data analysis (Wiggins and Crowston 2011, Eitzel et al. 2017). In that sense, any activity that relates to research (e.g., monitoring water quality or interviewing elders in a community) but that is done by nonprofessional researchers (e.g., lay citizens, students) can be considered CS, even if the activity is performed or framed in an educational or research institution. Normally explored in the context of "STEM" (science, technology, engineering, and math) or environmental education, CS school programs increase participants' knowledge base as well as their valuation of certain ecosystem services or natural elements (Ruiz-Mallén et al. 2016). Previously evaluated CS school programs focus on natural science issues such as biodiversity conservation or environmental monitoring, and not on biocultural issues such as TAeK conservation (Bela et al. 2016), for which it is unclear how these programs can affect issues such as students' valuation and access to TAeK. Indeed, although some research has investigated socio-cultural valuation of ecosystem services provided by TAeK-based practices (Calvet-Mir et al. 2012, Oteros-Rozas et al. 2014) and TAeK intergenerational transmission in industrialized contexts (Gómez-Baggethun et al. 2010, Calvet-Mir et al. 2016), most research in this field has focused on adults from indigenous populations who have relatively little exposure to other sources of TAeK, such as the Internet, or who have more connection to nature than do younger populations living in industrialized countries. Thus, there is a need to investigate the factors behind and the degree to which young generations in industrialized countries value and access traditional knowledge systems. More so, there is a need to evaluate the potential of CS school programs for TAeK conservation.

Here, we present results from a CS school program implemented in Catalan schools teaching agricultural technical studies. The program aimed at engaging the public in the documentation of TAeK through a "wiki"-like platform (https://www.conecte.es; Calvet-Mir et al. 2018, Benyei 2020). We explore students' (1) TAeK valuation, (2) access to TAeK, and (3) the impact of the CS program on (1) and (2). We end by discussing the implications of our results in terms of halting the erosion and promoting the maintenance of TAeK.

METHODS
We used a quasi-experimental design (i.e., an experimental design that lacks random assignment of subjects to treatment and control groups; Cook and Campbell 1979) that captured students' valuation and access to TAeK with a survey before and after an intervention consisting of exposing students to a CS school program (see Appendix 1 for details on the study context and CS program).

Intervention and sampling
Our intervention was designed based on the CONECT-e school program (see educational materials on the project's website) and had two activities. The first activity was a 50-min talk in which a researcher explained the concept of TAeK and gave some global and local examples of its importance, drivers of erosion, and potential recovery pathways. At the end of the talk, students were provided with a practical guide to document TAeK through interviews with elders. The second activity was a 50-min practical session in the school's computer room during which the students would enter the traditional knowledge they had gathered into an online wiki platform (https://www.conecte.es). Both sessions were separated by at least one month so that students would have time to interview elders. The students and their teachers had to sign a free prior informed consent sheet to be able to participate.

Because students in a class can be considered a captive population, our sampling strategy was voluntary sampling at the classroom level (i.e., sampling interested teachers that would volunteer to participate with their classes). Specifically, we invited teachers from all of the schools teaching agrarian technical studies[1] to participate in our study via personal contacts, social media, email, and telephone. Eleven teachers from nine schools volunteered to participate with their classes in our study (15 classes in total). We then systematically assigned classes to control ($N = 4$) and treatment ($N = 11$) groups (Tuckman and Harper 2012). Group assignments were done so that both groups were relatively equivalent in terms of the number of students (i.e., some of the treatment classes had as few as four students), geographical diversity, and study programs offered. To avoid potential interference by students sharing information, we assigned classes from the same school to the same group. Some of the teachers and students were lost to follow-up (i.e., only attended the first intervention activity or were not available to respond to the postintervention survey, even though they were all approached both physically and by email). This situation left us with two treatment groups, one with students who only attended the talk ($N = 59$) and one with students who attended the talk and did the practical activity ($N = 88$), and one control group ($N = 26$) with students who answered both surveys without doing any activity (total sample size = 173; see Fig. 1, Table 1).

Pre- and postintervention surveys
During the 2016–2017 academic year, we conducted the same survey at two times: once right before the first intervenion activity (but after clarifying the concept of TAeK), and once at the end of the school year, at least one month after the second intervention activity. Participants who dropped out and only did the first activity were also approached to complete the postintervention survey at the end of the school year (Table 2).

Our survey was based on a questionnaire that had three sections (Table 3; Appendix 2). The first section recorded students' valuation of TAeK using a Likert scale (Croasmun and Ostrom 2011). Based on literature exploring the values of traditional ecological knowledge (Reyes-García 2015), we proposed sentences with which students could agree or disagree on a five-point scale (1 = completely disagree, 5 = completely agree). Each sentence tried to capture the perceived value of TAeK regarding its contribution to biodiversity enhancement (V1), farm productivity (V2), identity promotion (V3), and farm sustainable

Fig. 1. Geographical locations of the schools teaching agricultural technical studies in Catalonia, Spain.
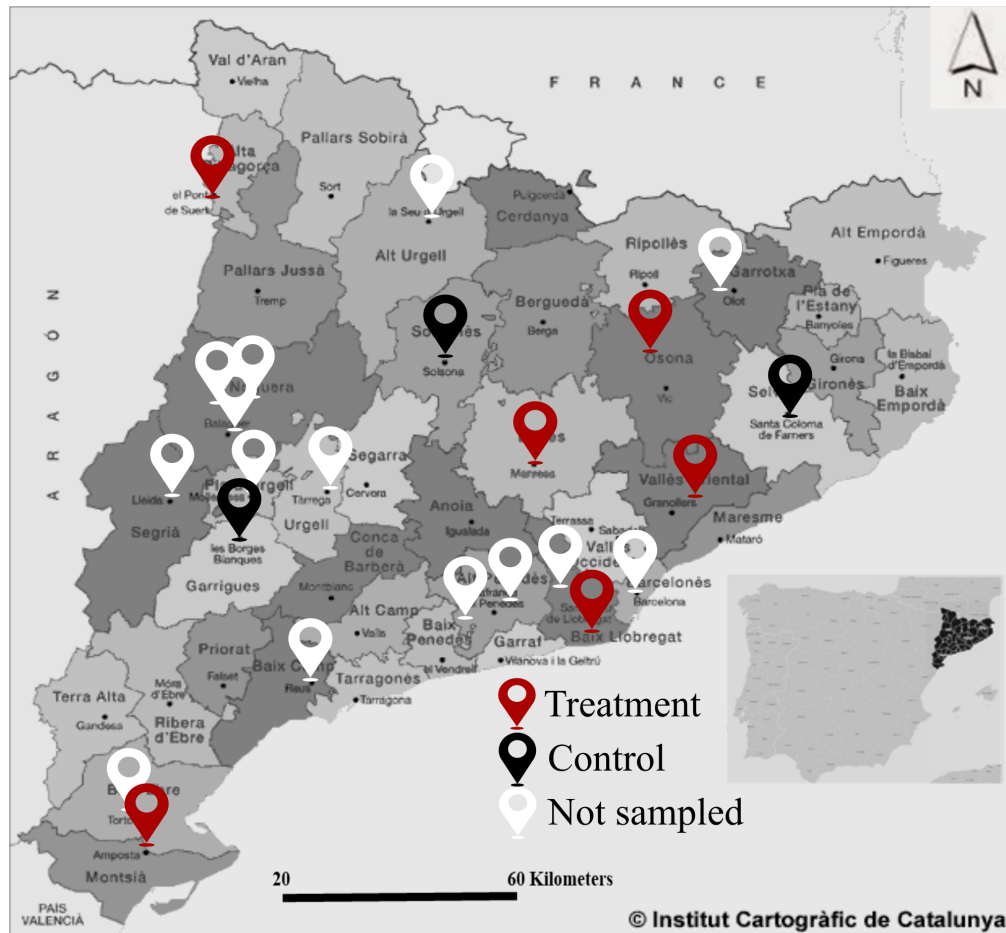
management (V4), and its validity as an updated knowledge base (V5), equally relevant as scientific knowledge (V6), and something that should be taught in schools (V7). To discourage automatic responding, some sentences were inverted (e.g., "TAeK does NOT contribute to ...").

The second section of the questionnaire gathered data regarding the frequency with which the students talked about TAeK (0 = never, 1 = rarely, 2 = frequently). This frequency was a proxy to measure access to TAeK. We included four potential ways of accessing TAeK: elders, including parents and grandparents (A1), friends (A2), classroom (A3), and digital or physical sources (A4).

The third section of the questionnaire gathered data on the students' socio-demographic characteristics, including year of birth, sex, actual residence (town name), study program (i.e., conventional agriculture, agroecology, natural resources management, gardening, agriculture and landscape, conventional animal health, forest management), and desired work sector (i.e., organic agriculture, conventional agriculture, environmental or forestry, gardening, or other). It also captured (using dummy variables) information related to the students' rurality, measured through family ties to the primary sector (1 = yes), current

employment in a natural resources related job (1 = yes), maintenance of a leisure home garden (1 = yes), and stated intention to live in a rural area in the future (1 = yes).

Variables

To construct a TAeK valuation index ($TAeK\_V_{sum}$), we first checked the internal correlation of the seven valuation scores using Pearson correlations ("cor.test" function, R Core Team 2018). Because we found internal consistency, we added the value of the seven individual topic scores ($\Sigma TAeK\_Vi$). The TAeK valuation index is expressed as:

$$TAeK\_V_{sum} = TAeK\_V1 + TAeK\_V2 + TAeK\_V3 + TAeK\_V4 + TAeK\_V5 + TAeK\_V6 + TAeK\_V7$$
(Eqn. 1)

This index could range from 7 (a student that strongly disagreed with all topics) to 35 (a student that strongly agreed with all topics).

To build a TAeK access index ($TAeK\_A_{sum}$), we added the scores for each of the four ways of accessing TAeK ($\Sigma TAeK\_Ai$) after checking for absence of internal association using Pearson Chi-squared tests ("chisq.test" function, R Core Team 2018). The

Table 1. Number of participants by sampled school, class level, program of study, and treatment group. *N* = 173.

School	Class level	Program of study	Treatment group	Number of students	Subtotal
S1	Basic	Conventional agriculture	Control	13	
S2	High	Forest management	Control	1	
	High	Agriculture and landscape	Control	3	
S3	High	Forest management	Control	9	26
S4	High	Forest management	Talk	24	
	Basic	Natural resources management	Talk	6	
S5	Basic	Agroecology	Talk	11	
	High	Agriculture and landscape	Talk	7	
S6	Basic	Agroecology	Talk	11	59
S7	High	Agriculture and landscape	Talk + Platform	19	
	High	Conventional animal health	Talk + Platform	23	
S8	High	Forest management	Talk + Platform	16	
	High	Agriculture and landscape	Talk + Platform	16	
	Basic	Gardening	Talk + Platform	11	
S9	Basic	Agroecology	Talk + Platform	3	88

TAeK access index is expressed as:

$$TAeK\_A_{sum} = TAeK\_A1 + TAeK\_A2 + TAeK\_A3 + TAeK\_A4 \quad \text{(Eqn. 2)}$$

This index could range from 0 (a student who never talked about TAeK, i.e., never accessed TAeK) to 8 (a student who frequently accessed TAeK through multiple ways).

We also recoded some of the socio-demographic variables (Table 3). The actual residence variable was recoded into a three-level categorical variable according to the classification of the town of residency as urban (1), intermediate (2), or rural (3) (Domínguez i Amorós et al. 2010). After examining the content and approach of the courses, the study program variable was recoded into a program theme categorical variable with three categories: alternative farming, grouping agroecology and landscape and agriculture programs (1); conventional farming, grouping conventional agriculture and conventional animal health (2); and environmental management, grouping gardening, natural resources management, and forest management (3).

Data analysis
To explore students' valuation and access to TAeK, we conducted descriptive analyses and linear mixed-effects models (LMMs) with the preintervention survey data. Specifically, we tested the association between individual covariates or fixed effects (i.e., age, sex, actual residence, program theme, desired work sector, and rurality variables) and the TAeK valuation and access indexes while controlling for interclassroom variation (random effects).

To measure the effects of the CS initiative on both students' valuation and access to TAeK, we conducted descriptive analyses of the postintervention survey data and Wilcoxon signed-rank tests and LMMs using data from both surveys. Specifically, we used nonparametric paired t-tests to compare mean scores of the indexes before and after the intervention (Pre_TAeK_V$_{sum}$ vs. Post_TAeK_V$_{sum}$, and Pre_TAeK_A$_{sum}$ vs. Post_TAeK_A$_{sum}$) and LMMs to test the effect of the treatment on the TAeK valuation and access indexes after the intervention (Post_TAeK_V$_{sum}$ and Post_TAeK_A$_{sum}$) while controlling for the baseline values (Pre_TAeK_V$_{sum}$ and Pre_TAeK_A$_{sum}$,

individual covariates, and interclassroom variation (random effects).

The LMMs were performed separately for each index. These models were built using manual stepwise backward regression, by which we began with all explanatory variables in the data set and progressively discarded those that did not significantly affect the outcome variable. Variables were only discarded if the model without them was not significantly different from the model with them (Crawley 2007). The final models were the ones that most parsimoniously explained the greatest variation in valuation and access indexes, for which variables included in each model are different. The assumptions of the final models were checked by examining the residuals (Appendix 3).

The final models were expressed by the following formulas:

$$Pre\_TAeK\_V_{sum} \sim 1 + age + leisure\_garden + (1 \mid class) \quad \text{(Eqn. 3)}$$

$$Pre\_TAeK\_A_{sum} \sim 1 + program\_theme + desired\_work + work\_rural\_nature + leisure\_garden + (1 \mid class) \quad \text{(Eqn. 4)}$$

$$Post\_TAeK\_V_{sum} \sim 1 + Pre\_TAeK\_V_{sum} + treatment + sex + desired\_work + (1 \mid class) \quad \text{(Eqn. 5)}$$

$$Post\_TAeK\_A_{sum} \sim 1 + Pre\_TAeK\_A_{sum} + treatment + desired\_residence + (1 \mid class) \quad \text{(Eqn. 6)}$$

For statistical analyses, we used RStudio version 1.0.153. To perform the Wilcoxon signed-rank tests, we used the "wilcox.test" function (R Core Team 2018). To conduct the mixed-effects models, we used the "lmerTest" and "lme4" packages (Bates et al. 2014). Mixed-effects models have been proven to be an effective way to account for school intervention effects in studies that include both categorical and continuous variables and that need to account for unbalanced data sets and random effects that arise during sampling, for instance, in the selection of a classroom (Wyman et al. 2010, Cunnings 2012). They are also described as being robust against violations of sphericity, homoscedasticity, and missing data (Quené and van den Bergh 2004, 2008, Kelder et al. 2005).

Table 2. Chronogram showing the timing of the intervention activities and surveys for each school.

Year of study	2016			2017					
Month of study	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Preintervention survey	S5	S9	S7	S4, S8	S6, S2, S3	S1			
Activity 1: talk	S5	S9	S7	S4, S8	S6				
Activity 2: platform						S7, S8, S9			
Postintervention survey								S1, S7, S8, S9	S4, S5, S6, S2, S3

RESULTS

Participant characteristics

Participants were mainly young men between 19 and 23 years old (83% male participants), although some were older. Two-thirds of the participants (63.2%) were studying a high-level program and one-third (31.8%) was studying a basic-level program. Programs were related to gardening, natural resource management, and forest management (39.9% of participants) as well as alternative (37.6%) and conventional farming (22.5%).

One-quarter of the participants (25%) wanted to work in organic farming, whereas 18.6% wanted to work in conventional farming. The remaining participants wanted to work in sectors other than agriculture, including environmental management or forestry (32.5%) and ornamental gardening (9.9%). Participants came from different areas in Catalonia, with 66.5% of them living in a rural or intermediate-rural town and 33.5% in an urban town. However, 73.8% of participants stated their intention to live in a rural area in the future. One-half (50.3%) of the participants came from a family with ties to the primary sector (farming, fishing, or forestry), and a similar proportion (49.4%) were or had been employed in a natural resources related job (e.g., in family farms or in fire prevention squads). Two-thirds of participants (64.5%) maintained a leisure home garden.

Traditional agroecological knowledge preintervention valuation and access

Results from the preintervention survey suggest that participants highly valued TAeK before our intervention (Fig. 2). On average, most participants showed a relatively strong agreement with sentences that stated TAeK's contribution to improving farm biodiversity (mean = 4.34 on a scale of one to five), productivity (mean = 3.82), and sustainable management (mean = 3.80). They also agreed with sentences stating that TAeK was updated (mean = 3.68) and as equally relevant as scientific knowledge (mean = 3.61). The statement they most strongly agreed with was the one stating that TAeK should be taught in schools (mean = 4.53), whereas they least strongly agreed with the one stating that TAeK contributed to their identity (mean = 3.22).

Moreover, results from the LMMs show that the TAeK valuation index (Pre_TAeK_V$_{sum}$, mean = 26.99, SD = 3.49; maximum possible score of 35) bears a positive and statistically significant association with the participant's age (F = 8.6647, P < 0.01) and maintenance of a leisure home garden (F = 3.9348, P < 0.05; Fig. 3, Table 4; Appendix 4).

On the contrary, most participants rarely talked about TAeK with people around them, or in other words, they rarely accessed TAeK (Fig. 4). Those with whom they most often talked about TAeK were their elders (38.7% of participants stated talking frequently about TAeK with their elders), whereas those with whom they least often talked about TAeK were their classmates (only 9.8% of participants stated talking frequently about TAeK in the classroom). Also, only 30.6% of participants stated talking frequently about TAeK with friends and only 23.9% frequently consulted TAeK in digital or physical sources.

Fig. 2. Box plots of participants' valuation scores for the different traditional agroecological knowledge value statements before the intervention.
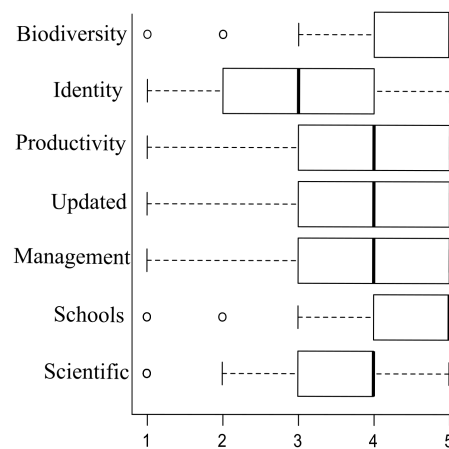

Fig. 3. Preintervention traditional agroecological knowledge (TAeK) valuation index vs. age of the participant and whether the particpant maintained a leisure home garden.
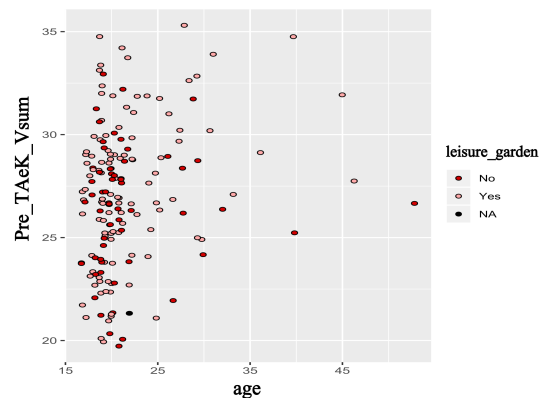
Table 3. Description of variables used in the analyses. TAeK = traditional agroecological knowledge.

Variable	Code	Type	Attribute
TAeK perceived contribution to biodiversity enhancement	TAeK_V_1	Interval	Scale 1–5
TAeK perceived contribution to farm productivity	TAeK_V_2	Interval	Scale 1–5
TAeK perceived contribution to identity promotion	TAeK_V_3	Interval	Scale 1–5
TAeK perceived contribution to farm sustainable management	TAeK_V_4	Interval	Scale 1–5
TAeK perceived validity as an updated knowledge base	TAeK_V_5	Interval	Scale 1–5
TAeK perceived validity as equally relevant as scientific knowledge	TAeK_V_6	Interval	Scale 1–5
TAeK perceived validity as something that should be taught in schools	TAeK_V_7	Interval	Scale 1–5
TAeK valuation index	TAeK_V_{sum}	Continuous	ΣTAeK_V_i
How frequently students talked about TAeK with elders	TAeK_A_1	Interval	Scale 0–2
How frequently students talked about TAeK with friends	TAeK_A_2	Interval	Scale 0–2
How frequently students talked about TAeK in the classroom	TAeK_A_3	Interval	Scale 0–2
How frequently students consulted TAeK in digital or physical sources	TAeK_A_4	Interval	Scale 0–2
TAeK access index	TAeK_A_{sum}	Continuous	Σ TAeK_A_i
Age	age	Continuous	Converted year of birth
Sex	sex	Dummy	1 = female
Actual residence	residence	Categorical	1 = urban
			2 = intermediate
			3 = rural
Program theme	program_theme	Categorical	1 = alternative farming
			2 = conventional farming
			3 = environmental management
Desired work sector	desired_work	Categorical	1 = organic agriculture
			2 = conventional agriculture
			3 = environmental/forestry
			4 = gardening
			5 = other
Family ties to the primary sector	family_primary	Dummy	1 = yes
Current employment in a natural resources related job	work_rural_nature	Dummy	1 = yes
Maintenance of a leisure home garden	leisure_garden	Dummy	1 = yes
Intention to live in a rural area in the future	desired_residence	Dummy	1 = yes
Treatment	treatment	Categorical	0 = control
			1 = only talk
			2 = talk and practical activity

Fig. 4. Preintervention frequency of access to traditional agroecological knowledge (TAeK) for the different access pathways.
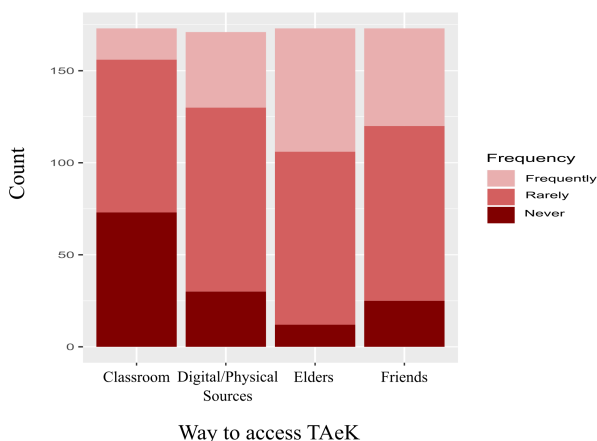
Results from the LMMs show that the TAeK access index (Pre_TAeK_A_{sum}, mean = 4.21, SD = 1.83; maximum possible score of 8) is associated with the participants' program theme (F = 12.0204, $P < 0.001$), desired work sector (F = 2.9547, $P < 0.05$), employment in a natural resources related job (F = 9.3896, $P < 0.01$), and maintenance of a leisure home garden (F = 13.6958, $P < 0.001$; Fig. 5, Table 5; Appendix 4). Indeed, participants studying conventional farming and environmental management programs accessed TAeK significantly less often than participants in alternative farming programs. Also, participants who wanted to work in the conventional agriculture, environmental or forestry, gardening, and other sectors accessed TAeK significantly less often than those who wanted to work in the organic agriculture sector. Finally, participants employed in a natural resources related job or maintaining a leisure home garden accessed TAeK significantly more often than did their peers.
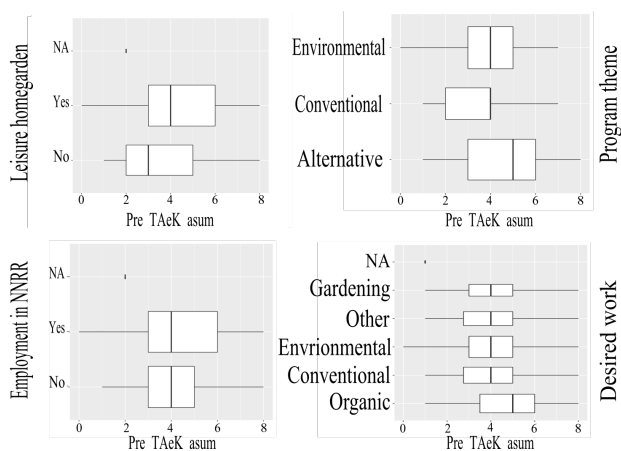
Intervention effects on traditional agroecological knowledge valuation and access

The mean TAeK valuation index score was not significantly higher after the intervention (Post_TAeK_V_{sum}, mean = 26.86, SD = 3.56, $P = 0.5516$; Fig. 6). However, there seems to be some variation in TAeK valuation when looking at specific questions, particularly TAeK's perceived contribution to identity promotion (with an increase in mean score from 3.22 to 3.31 on a scale of 1–5), TAeK's perceived validity as an updated knowledge base (from 3.68 to 3.71), and TAeK's perceived validity as equally relevant as scientific knowledge (from 3.61 to 3.76).

Table 4. Best fitting model for the preintervention traditional agroecological knowledge valuation index (Pre_TAeK_V$_{sum}$). The most parsimonious linear mixed model was fit using restricted maximum likelihood (REML) methods. The *t*-tests use Satterthwaite approximations to degrees of freedom. Model formula = Pre_TAeK_V$_{sum}$ ~ 1 + age + leisure_garden + (1 | class). REML criterion at convergence = 899.4. Number of observations = 171, groups: class, 15.

Fixed effect	Estimate	Standard error	Degrees of freedom	*t*	*P*
Intercept	23.17114	1.10926	168	20.89	< 2e-16
age	0.14263	0.04723	168	3.02	0.00292
leisure_garden_yes	1.14675	0.53340	168	2.15	0.03299

Fig. 5. Box plots of the distribution of the preintervention traditional agroecological knowledge (TAeK) access index for variables that were significantly associated with it.


Fig. 6. Frequency distributions of the preintervention (A) and postintervention (B) traditional agroecological knowledge (TAeK) valuation index.
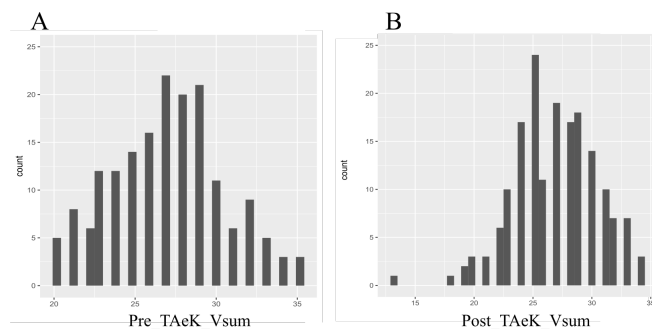
Results from the LMMs suggest that these variations in TAeK valuation might be associated with our intervention (*F* = 2.2583, *P* = 0.15463) but also with other factors. Controlling for participants' TAeK valuation before the intervention, participation in the first intervention activity (the talk, T1) had a significant direct and positive effect on participants' valuation of TAeK. Participation in both intervention activities (talk and practical activity, T2) was also directly and positively associated with participants' TAeK valuation, although the association was not statistically significant. Participants' gender (*F* = 5.4467, *P* < 0.05) and desired work sector (*F* = 3.4442, *P* < 0.05) were also associated with TAeK valuation after the intervention: women valued TAeK significantly less than did men, as did participants willing to work in the conventional agriculture, environmental or forestry, and other sectors when compared to those willing to work in the organic agriculture sector (Fig. 7, Table 6; Appendix 4).

Fig. 7. Postintervention traditional agroecological knowledge (TAeK) valuation index vs. preintervention TAeK valuation index by treatment. Data points falling above the diagonal line correspond to participants that valued TAeK higher after than before the intervention.
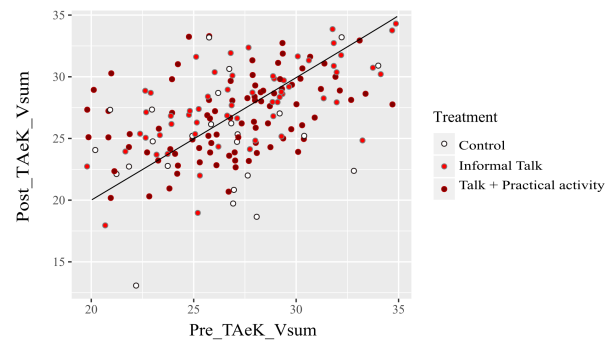

The effect of the intervention was more evident when looking at access to TAeK. Indeed, although results were not statistically significant, participants seem to have accessed TAeK more often after than before the intervention (Post_TAeK_A$_{sum}$, mean = 4.39, SD = 1.63, *P* = 0.1701; Fig. 8). Specifically, compared with the answers before the intervention, participants talked more frequently about TAeK with friends and in the classroom, and also consulted TAeK more frequently in digital and physical sources after the intervention. In fact, the proportion of students that never talked about TAeK with friends or in the classroom went down 6.4% and 19.1%, respectively.

Table 5. Best fitting model for the preintervention traditional agroecological knowledge access index (Pre_TAeK_A$_{sum}$). The most parsimonious linear mixed model was fit using restricted maximum likelihood (REML) methods. The t-tests use Satterthwaite approximations to degrees of freedom. Model formula = Pre_TAeK_A$_{sum}$ ~ 1 + program_theme + desired_work + work_rural_nature + leisure_garden + (1 | class). REML criterion at convergence = 638.2. Number of observations = 171, groups: class, 15.

Fixed effect	Estimate	Standard error	Degrees of freedom	t	P
Intercept	4.6797	0.3650	162	12.819	< 2e-16
program_theme = conventional farming	−1.8879	0.3887	162	−4.857	2.79e-06
program_theme = environmental management	−0.7877	0.3216	162	−2.449	0.015397
desired_work = conventional agriculture	−0.7932	0.3916	162	−2.025	0.044475
desired_work = environmental or forestry	−0.9946	0.3658	162	−2.719	0.007264
desired_work = other	−0.9092	0.4121	162	−2.206	0.028776
desired_work = gardening	−1.2757	0.4936	162	−2.584	0.010639
work_rural_nature = yes	0.7757	0.2532	162	3.064	0.002557
leisure_garden = yes	0.9894	0.2673	162	3.701	0.000294

Fig. 8. Frequency distributions of the preintervention (A) and postintervention (B) traditional agroecological knowledge (TAeK) access index.
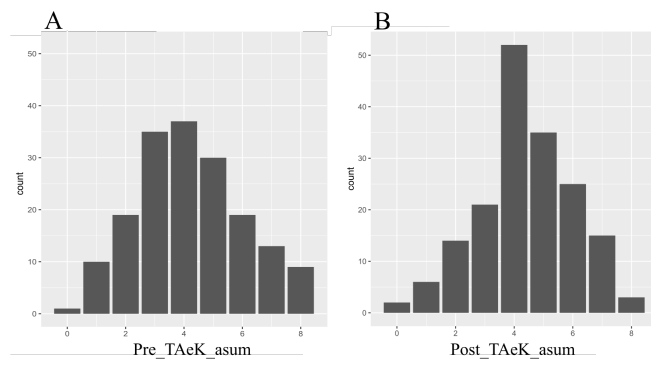
The LMMs showed that, controlling for the preintervention answers, both treatments had a significant direct and positive effect on the postintervention TAeK access index (F = 4.2503, P < 0.05). In other words, attending the talk and using the CONECT-e platform significantly increased the frequency with which participants talked about TAeK. Access to TAeK after the intervention was also positively associated with a participant's desire to live in a rural area in the future (F = 8.2162, P < 0.01; Fig. 9, Table 7; Appendix 4).

DISCUSSION
Our results contribute to understanding valuation and access to TAeK among young rural populations of industrialized countries. Moreover, they also shed light on the potential of CS school programs in terms of increasing valuation and access to TAeK. Before discussing these results, we address some of the caveats that might have potentially affected them.

Caveats
The first caveat of our study relates to potential sampling biases. Schools selected for the study mainly focused on agricultural or environmental education, and most of them were located in rural areas where TAeK-holders live. Although this sampling strategy makes sense in the context of our study, it also reduces the external

validity of the results because the study participants do not represent the average youth in industrialized countries, but are a subsample with previous interest in agricultural and environmental topics and that have easy access to traditional knowledge holders. Moreover, our study faces self-selection biases for two reasons. First, teachers voluntarily enrolled their students in the activity, which might result in a self-selection of students with previously interested teachers that could, in turn, be influencing their students. Second, students were able to abandon the study by not answering the postintervention survey (in fact 19.5% did so), which might have biased our sample toward students who are more willing to participate in our activities.

Fig. 9. Postintervention traditional agroecological knowledge (TAeK) access index vs. preintervention TAeK access index by treatment. Data points falling above the diagonal line correspond to participants that accessed TAeK more frequently after than before the intervention.
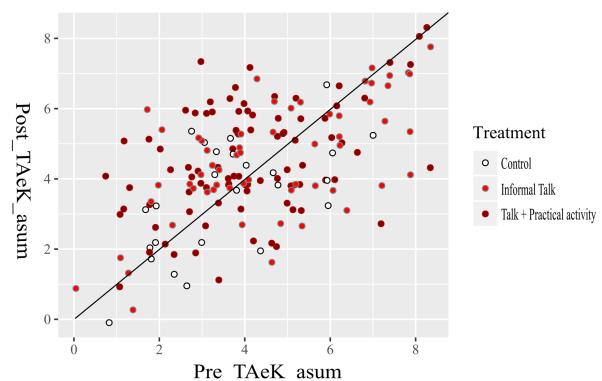
Second, the survey design might have affected participants' responses. On the one hand, the use of a five-point Likert scale limited the valuation score's range. This meant that if a participant valued TAeK very highly before the intervention (5), he/she would not be able to increase this value after the intervention. In this case, the null (or negative) valuation change probably relates more to the measurement instrument than to a real valuation change.

Table 6. Best fitting model for the postintervention traditional agroecological knowledge valuation index (Post_TAeK_V$_{sum}$). The most parsimonious linear mixed model was fit using restricted maximum likelihood (REML) methods. The t-tests use Satterthwaite approximations to degrees of freedom. Model formula = Post_TAeK_V$_{sum}$ ~ 1 + Pre_TAeK_V$_{sum}$ + treatment + sex + desired_work + (1 | class). REML criterion at convergence = 843.6. Number of observations = 172, groups: class, 15.

Fixed effect	Estimate	Standard error	Degrees of freedom	t	P
Intercept	15.02391	1.88501	147.57539	7.970	3.97e-13
Pre_TAeK_V$_{sum}$	0.44823	0.06416	157.32076	6.987	7.51e-11
treatment = talk	1.87197	0.87023	14.53101	2.151	0.04873
treatment = talk+practical	1.33078	0.79913	11.38433	1.665	0.12311
gender = female	−1.40591	0.61017	162.66098	−2.304	0.02248
desired_work = conventional agriculture	−2.32367	0.73306	148.06599	−3.170	0.00185
desired_work = environmental or forestry	−1.74521	0.63195	105.78336	−2.762	0.00678
desired_work = other	−1.70314	0.74548	162.04090	−2.285	0.02363
desired_work = gardening	−0.65308	0.86116	142.09345	−0.758	0.44948

On the other hand, the fact that the surveys were done with the teacher and researcher in the classroom could lead to social desirability response bias (van de Mortel 2008), meaning that the students might have reported high valuation and access to TAeK just because they thought they were expected to do so.

The third caveat relates to the selection of variables. We focused on two of the variables (valuation and access) that the literature has highlighted as key to the maintenance of TAeK (Gómez-Baggethun et al. 2010, Hernández-Morcillo et al. 2014). However, there could be unmeasured confounding variables for which we cannot assume that students who value highly and talk a lot about TAeK would be more likely to use TAeK in the future.

A final caveat relates to the lack of more baseline and longitudinal measures. Although the access to TAeK could be indicative of TAeK transmission in the sense that there is a chance for transmission if a person talks frequently about TAeK, we cannot demonstrate that the transmission was effective in the long term unless we measure the baseline knowledge and whether students actually retained the information after some time.

To value or not to value
Findings from this work point out two main issues in relation to the devaluation of TAeK. First, our results point out that students who enroll in agricultural technical studies in Catalonia value TAeK quite highly. In fact, they strongly agree with statements related to the importance of including TAeK in school curricula and to the equal value of TAeK and scientific knowledge. Although these results may only be representative of our sample, they show a tendency toward overcoming the previously reported devaluation of traditional knowledge systems in favor of "expert" knowledge systems (Agrawal 1995, Nadasdy 1999, Naredo 2004, Gómez-Baggethun et al. 2010, Burke and Heynen 2014, Hernández-Morcillo et al. 2014). Indeed, our results might be indicative of a revalorization of TAeK by young generations of future alternative farmers, a trend that could break with the abandonment of TAeK reported in Spain, and in Europe in general (Naredo 2004, Hernández-Morcillo et al. 2014).

Second, our results highlight that the most important factors affecting the valuation of TAeK among agricultural technical students in Catalonia are age, maintenance of a leisure home garden, and willingness to work in the organic farming sector. Older students, students who spend leisure time working in a home

garden, and students who would like to work in the organic sector in the future value TAeK more than their peers do. Considering that TAeK is experience based, learner centered, and acquired through contextualized interaction with community members (Lancy 1996, Hunn 2002, Reyes-García et al. 2010, McCarter and Gavin 2011), it seems logical that older students, who have been able to spend more time with elders and in nature, and who are willing to do so in the future, also value TAeK more. Most importantly, our results could be understood as a call for including hands-on gardening activities in the school curricula of younger students to promote the revalorization of TAeK.

Accessing traditional agroecological knowledge
TAeK was most frequently accessed by talking with elders and was rarely accessed by talking about TAeK in class. Talking about TAeK with friends and consulting digital sources occurred more frequently than talking about TAeK in class but was still not very frequent. Assuming that talking about TAeK can mean opening the possibility to TAeK transmission, and considering the different transmission pathways described in the introduction, our results suggest that in our case study, oblique and vertical transmission pathways (talking with elders) were more frequent than horizontal pathways (talking in class and with friends). Moreover, the overall use of these pathways was positively associated with studying an alternative farming program, working in a natural resources related job, willingness to work in the organic farming sector, willingness to live in a rural area in the future, and maintenance of a leisure home garden. These results are not surprising; previous research shows that the main pockets of TAeK in Spain are held by elderly rural populations and that schools rarely include TAeK in their curricula (Reyes-García et al. 2014, Ramet et al. 2018), for which students need to access TAeK through pathways outside the classroom. The finding, however, has some potential implications for TAeK maintenance.

First, when analyzing the use of different transmission pathways, several authors have highlighted the importance of "scaffolding", or learning from a more knowledgeable person (normally an elder), particularly for the acquisition of complex skills (Reiser and Tabak 2014, Reyes-García et al. 2016). This concept applies to the transmission of TAeK, which requires the intervention of a more knowledgeable person who explains and guides the learner through the complexity of TAeK-based practices. Thus, in the context of traditional knowledge systems, the literature reports

Table 7. Best fitting model for the postintervention traditional agroecological knowledge access index (Post_TAeK_A$_{sum}$). The most parsimonious linear mixed model was fit using restricted maximum likelihood (REML) methods. The t-tests use Satterthwaite approximations to degrees of freedom. Model formula = Post_TAeK_A$_{sum}$ ~ 1 + Pre_TAeK_A$_{sum}$ + Treatment + desired_residence + (1 | class). REML criterion at convergence = 583.6. Number of observations = 172, groups: class, 15.

Fixed effect	Estimate	Standard error	Degrees of freedom	t	P
Intercept	1.39638	0.36485	167	3.827	0.000183
Pre_TAeK_A$_{sum}$	0.43624	0.05608	167	7.778	7.23e-13
treatment = talk	0.75799	0.31202	167	2.429	0.016187
treatment = talk+practical	0.84278	0.29317	167	2.875	0.004571
desired_residence = yes	0.65787	0.22951	167	2.866	0.004687

oblique and vertical transmission as key transmission pathways (see, for instance, Lozada et al. 2006). However, the literature also highlights that horizontal transmission is very relevant for TAeK maintenance because similar aged peers will be able to track changes, becoming the best source of updated information (Reyes-García et al. 2016). Thus, considering our results, more emphasis should be placed on promoting horizontal TAeK transmission to improve the TAeK-based skills of future farmers and contribute to TAeK maintenance.

Second, independently of the transmission pathway used, and to halt TAeK erosion, our results call for reinforcing those factors favoring access to TAeK. For instance, because access to TAeK was positively associated with studying, working, and spending leisure time in alternative farming, supporting these activities and facilitating hands-on experiences related to TAeK might be key to encouraging TAeK transmission, a crucial step in TAeK maintenance (Abioye et al. 2014, Llerena del Castillo and Espinet 2017, Eugenio and Aragón 2018).

CONECT-e: seeds of change
A main finding of this work is that including explanations and technology-mediated exercises related to TAeK documentation in school activities had a positive effect both on the valuation of and access to this knowledge system. Moreover, the resources needed to achieve some results are relatively modest (i.e., two 50-min sessions, in our case). This result helps us unveil the potential of CS school programs as tools for TAeK conservation. Previous literature on the field of environmental education in general and CS in particular had reported positive effects of contextualized school programs in the valuation and acquisition of indigenous ecological knowledge (Ruiz-Mallen et al. 2009, Shukla et al. 2017). Still, to our knowledge, this is the first time a CS school program developed in an industrialized context was found to have a positive impact on the valuation of and access to TAeK. However, two issues must be highlighted in relation to the limits of this tool to halt TAeK erosion.

First, we must be careful when interpreting our results because the differences in mean valuation and access scores before and after the intervention were not statistically significant. Moreover, the effect of the CS program was lower on students' valuation than on their access to TAeK. This result could be caused by our measurement methods (see *Discussion: Caveats*), but it could also signal limitations of CS approaches when trying to improve TAeK valuation. Still, even if the intervention's impact was not so high, our results highlight that these types of programs encourage

students to talk more about TAeK, a key aspect for its revitalization. Longitudinal studies are needed to assess whether the effect of this type of program increases over time.

Second, we must consider that the intervention had effects even without the use of the CS platform. Just attending the talk was positively associated with students' valuation and access to TAeK. This result highlights that the initial approach of the CONECT-e project (using an online platform to promote TAeK sharing through intergenerational activities) might not be the only way to halt TAeK devaluation and lack of transmission among younger generations in industrialized contexts. Indeed, it is possible that simpler efforts, such as including TAeK in school curricula though informal talks, might already be a good enough tool to increase TAeK's perceived value and transmission, as has already been reported in the literature (McCarter and Gavin 2014, Tang and Gavin 2016).

CONCLUSION
This study contributes to the understanding of how to halt TAeK erosion by exploring the factors behind valuation and access to TAeK and by evaluating the effect of a CS school program on both. Four main conclusions can be drawn from this research. First, the study population, i.e., youth studying agricultural technical programs in Catalonia, values TAeK highly and talks relatively frequently about it with elders. Second, encouraging hands-on activities such as home gardening and reinforcing students' interest in alternative farming may increase students' valuation and access to TAeK. Third, relatively simple school programs can have a positive effect on how much and how often the young generations of future farmers in industrialized contexts value and access TAeK. Finally, the promotion of these types of initiatives could be critical for agroecological transitions because they require young farmers to value and access TAeK. Longitudinal studies are required to test whether and why students who engaged in a CS school program focusing on TAeK documentation actually put this knowledge to practice in their future life, which is the only way for this knowledge to be kept alive.

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[1] The agrarian technical studies taught in Catalonia can be basic-level studies (i.e., students are only required to have completed secondary high school) or high-level studies (i.e., students are required to have completed university preparatory courses) and include programs focusing on landscaping, forest management, and agricultural production, among others.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.
php/11471

Data Availability Statement:

The data/code that support the findings of this study are available on request from the corresponding author. The data/code are not publicly available due to restrictions (they contain information that could compromise the privacy of research participants).

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Appendix 1. Study context and citizen science program

Study context

Catalonia is situated in the north-east of Spain (Figure 1 of the manuscript). Despite its population density (234.3 inh./km^2) and the importance of the services sector (80% of Catalan GDP, IDESCAT 2017), most of its territory is still catalogued as rural or intermediate-rural based on indicators of population density and economic activity (73% of the municipalities have less than 130 inh./km^2 and 48% have a strong or moderate presence of the agrarian sector, Domínguez i Amorós et al. 2010).

As in most of Europe, agricultural intensification has shaped the Catalan rural sector with severe environmental, social and demographic consequences, including nitrification of soils, loss of biodiversity, rural depopulation, and loss of TAeK (Naredo 2004; Gómez-Baggethun et al. 2010; Menció et al. 2011). In the spirit of this intensification and modernization, in the 1970's and 80's agricultural technical schools were opened in some Catalan rural areas. The original aim of these schools was to continue the mission of the agricultural extension schools founded in the 1950's and 60's, i.e., to promote agricultural extension systems and train future farmers in the techniques and practices of the green revolution (Minguet Pla 2009; Generalitat de Catalunya 2018). However, the increasing demand for more sustainable agricultural systems led to the introduction of organic agriculture as part of the curriculum of some of these schools, and to the opening of new schools and curricular programs that incorporate training on agroecological techniques and environmental management. Moreover, agricultural technical studies have also started to be an option in other high schools from rural and intermediate-rural areas.

Nowadays, 23 schools teach agricultural technical studies in Catalonia (7 high schools, 14 agricultural technical schools, and 2 private schools) covering the four Catalan provinces (Minguet Pla 2009; Generalitat de Catalunya 2018, Figure 1). The students (about 1300 in 2009) receive training in a specific profession after finishing the secondary school basic level. The offered study programs vary from agroecological farming and conventional farming to ornamental gardening or forest management, and last between two and four years.

The citizen science school program

CONECT-e is a citizen science initiative that was born to document, share, and protect Traditional Ecological Knowledge (TEK) as a commons and in a participatory way (Calvet-Mir et al. 2018, Reyes-García et al. 2018a). The initiative's main tool is an online wiki platform in which registered users can enter traditional knowledge related to wild or cultivated plants (www.conecte.es).

The initiative has been co-designed by researchers from seven institutions (including most of this manuscript's authors) and the Spanish seed network ("Red de Semillas: Resembrando e Intercambiando"), a non-profit, decentralized organization that brings together more than 20 regional and local seed networks from all over Spain (Red de Semillas 2015). The project's intuition is that TAeK documentation, sharing and protection could be boosted by the use of information technologies, as these technologies help to de-centralize data collection and allow protecting the knowledge in the public domain under copy-left licenses (Calvet-Mir et al. 2018, Reyes-García et al. 2018b).

To bridge the technological gap that traditional knowledge holders might face, young volunteers were recruited through dissemination activities (e.g., articles in the news, presentations in local fairs, workshops within university volunteer programs), the idea being that these volunteers would be the link between the elder's knowledge and the digital platform. As part of this dissemination plan, a school program was also designed to recruit technologically literate students with an interest in nature and farming (i.e., agricultural technical students) that would interview their elders and enter their TAeK in the platform.

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Appendix 2. Questionnaire

The questionnaire used in this study can be found online here:

https://docs.google.com/forms/d/e/1FAIpQLSdOwJxwot-opyyqSKwwh-WDDHa2kiErCQUTVZGg7-gJ4sNE8w/viewform?usp=sf_link

Appendix 3. R script for LMMs

~ Pre value

```
fit0a<-lmer(Pre_TAeK_vsum ~ 1 + module_theme + age + Female +
  Desired_work_sector + residence + Family_primary_sector + Work_rural_nature +
  Leisure_garden + desired_residence + (1|class), data = schools_prepost,REML =
  FALSE)

summary(fit0a)

fit0b<-lmer(Pre_TAeK_vsum ~ 1 + age + Female + Desired_work_sector + residence
  + Family_primary_sector + Work_rural_nature + Leisure_garden +
  desired_residence + (1|class), data = schools_prepost,REML = FALSE)

anova(fit0a,fit0b)
summary(fit0b)

fit1<-lmer(Pre_TAeK_vsum ~ 1 + age + Female + residence + Family_primary_sector
  + Work_rural_nature + Leisure_garden + desired_residence + (1|class), data =
  schools_prepost,REML = FALSE)

anova(fit0b,fit1)
summary(fit1)

fit2<-lmer(Pre_TAeK_vsum ~ 1 + age + Female + residence + Work_rural_nature +
  Leisure_garden + desired_residence + (1|class), data = schools_prepost,REML =
  FALSE)

anova(fit1,fit2)
summary (fit2)

fit3<-lmer(Pre_TAeK_vsum ~ 1 + age + Female + residence + Leisure_garden +
  desired_residence + (1|class), data = schools_prepost,REML = FALSE)

anova(fit2,fit3)
summary(fit3)

fit4<-lmer(Pre_TAeK_vsum ~ 1 + age + Female + residence + Leisure_garden +
  (1|class), data = schools_prepost,REML = FALSE)

anova(fit3,fit4)
summary(fit4)

fit5<-lmer(Pre_TAeK_vsum ~ 1 + age + residence + Leisure_garden + (1|class), data =
  schools_prepost,REML = FALSE)

anova(fit4,fit5)
summary(fit5)
```

```r
fit6<-lmer(Pre_TAeK_vsum ~ 1 + age + Leisure_garden + (1|class), data =
  schools_prepost,REML = FALSE)

anova(fit5,fit6)
summary(fit6)

fitfinalvalue<-lmer(Pre_TAeK_vsum ~ 1 + age + Leisure_garden + (1|class), data =
  schools_prepost,REML = TRUE)

summary(fitfinalvalue)
anova(fitfinalvalue)
plot(fitfinalvalue)
plot(allEffects(fitfinalvalue))
ranef(fitfinalvalue)

### ~ Pre transmission ####

fit0a<-lmer(Pre_TAeK_asum ~ 1 + module_theme + age + Female +
  Desired_work_sector + residence + Family_primary_sector + Work_rural_nature +
  Leisure_garden + desired_residence + (1|class), data = schools_prepost,REML =
  FALSE)

summary(fit0a)

fit1<-lmer(Pre_TAeK_asum ~ 1 + module_theme + age + Desired_work_sector +
  residence + Family_primary_sector + Work_rural_nature + Leisure_garden +
  desired_residence + (1|class), data = schools_prepost,REML = FALSE)

anova(fit0a,fit1)
summary(fit1)

fit2<-lmer(Pre_TAeK_asum ~ 1 + module_theme + age + Desired_work_sector +
  residence + Work_rural_nature + Leisure_garden + desired_residence + (1|class),
  data = schools_prepost,REML = FALSE)

anova(fit1,fit2)
summary(fit2)

fit3<-lmer(Pre_TAeK_asum ~ 1 + module_theme + age + Desired_work_sector +
  Work_rural_nature + Leisure_garden + desired_residence + (1|class), data =
  schools_prepost,REML = FALSE)

anova(fit2,fit3)
summary(fit3)

fit4<-lmer(Pre_TAeK_asum ~ 1 + module_theme + age + Desired_work_sector +
  Work_rural_nature + Leisure_garden + (1|class), data = schools_prepost,REML =
  FALSE)

anova(fit3,fit4)
```

```
summary(fit4)

fit5<-lmer(Pre_TAeK_asum ~ 1 + module_theme + Desired_work_sector +
  Work_rural_nature + Leisure_garden + (1|class), data = schools_prepost,REML =
  FALSE)

anova(fit4,fit5)

schools_prepost_test3<-schools_prepost%>%
  na.exclude(age)

fit4<-lmer(Pre_TAeK_asum ~ 1 + module_theme + age + Desired_work_sector +
  Work_rural_nature + Leisure_garden + (1|class), data =
  schools_prepost_test3,REML = FALSE)

fit5<-lmer(Pre_TAeK_asum ~ 1 + module_theme + Desired_work_sector +
  Work_rural_nature + Leisure_garden + (1|class), data =
  schools_prepost_test3,REML = FALSE)

anova(fit4,fit5)
summary(fit5)

fitfinaltransmission<-lmer(Pre_TAeK_asum ~ 1 + module_theme +
  Desired_work_sector + Work_rural_nature + Leisure_garden + (1|class), data =
  schools_prepost,REML = TRUE)

summary(fitfinaltransmission)
anova(fitfinaltransmission)
plot(fitfinaltransmission)
plot(allEffects(fitfinaltransmission))
ranef(fitfinaltransmission)

#### ~ Value/Pre-post~ ####

fit0<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + module_theme +
  age + Female + Desired_work_sector + residence + Family_primary_sector +
  Work_rural_nature + Leisure_garden + desired_residence + (1|class), data =
  schools_prepost,REML = FALSE)
summary(fit0)

fit1<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + module_theme +
  age + Female + Desired_work_sector + residence + Family_primary_sector +
  Leisure_garden + desired_residence + (1|class), data = schools_prepost,REML =
  FALSE)

anova(fit0,fit1)
summary(fit1)
```

```
fit2<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + age + Female +
   Desired_work_sector + residence + Family_primary_sector + Leisure_garden +
   desired_residence + (1|class), data = schools_prepost,REML = FALSE)

anova(fit1,fit02)
summary(fit2)

fit3<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + age + Female +
   Desired_work_sector + Family_primary_sector + Leisure_garden +
   desired_residence + (1|class), data = schools_prepost,REML = FALSE)

anova(fit2,fit3)
summary(fit3)


fit4<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + age + Female +
   Desired_work_sector + Leisure_garden + desired_residence + (1|class), data =
   schools_prepost,REML = FALSE)

anova(fit3,fit4)
summary(fit4)

fit5<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + age + Female +
   Desired_work_sector + desired_residence + (1|class), data = schools_prepost,REML
   = FALSE)

anova(fit4,fit5)
summary(fit5)

fit6<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + Female +
   Desired_work_sector + desired_residence + (1|class), data = schools_prepost,REML
   = FALSE)

anova(fit5,fit6)

schools_prepost_test<-schools_prepost%>%
  na.exclude(age)

fit5<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + age + Female +
   Desired_work_sector + desired_residence + (1|class), data =
   schools_prepost_test,REML = FALSE)

fit6<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + Female +
   Desired_work_sector + desired_residence + (1|class), data =
   schools_prepost_test,REML = FALSE)

anova(fit5,fit6)
summary(fit6)
```

```r
fit7<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + Female +
    Desired_work_sector + (1|class), data = schools_prepost,REML = FALSE)

anova(fit6,fit7)
summary(fit7)

fitfinalvalue<-lmer(Post_TAeK_vsum ~ 1 + Pre_TAeK_vsum + Treatment + Female +
    Desired_work_sector + (1|class), data = schools_prepost, REML = TRUE)

summary(fitfinalvalue)
anova(fitfinalvalue)
plot(fitfinalvalue)
plot(allEffects(fitfinalvalue))
ranef(fitfinalvalue)

#### ~ Transmission/Pre-post~ ####

fit0<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + module_theme + age +
Female + Desired_work_sector + residence + Family_primary_sector + Work_rural_nature +
Leisure_garden + desired_residence + (1|class), data = schools_prepost,REML = FALSE)

summary(fit0)


fit1<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + module_theme + age +
Female + residence + Family_primary_sector + Work_rural_nature + Leisure_garden +
desired_residence + (1|class), data = schools_prepost,REML = FALSE)

anova(fit0,fit1)

summary(fit1)


fit2<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age + Female + residence +
Family_primary_sector + Work_rural_nature + Leisure_garden + desired_residence + (1|class),
data = schools_prepost,REML = FALSE)

anova(fit1, fit2)

summary(fit2)


fit3<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age + residence +
Family_primary_sector + Work_rural_nature + Leisure_garden + desired_residence + (1|class),
data = schools_prepost,REML = FALSE)

anova(fit2,fit3)

summary(fit3)
```

```
fit4<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age +
Family_primary_sector + Work_rural_nature + Leisure_garden + desired_residence + (1|class),
data = schools_prepost,REML = FALSE)

anova(fit3,fit4)

schools_prepost_test<-schools_prepost%>%

  na.exclude(residence)

fit3<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age + residence +
Family_primary_sector + Work_rural_nature + Leisure_garden + desired_residence + (1|class),
data = schools_prepost_test,REML = FALSE)

fit4<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age +
Family_primary_sector + Work_rural_nature + Leisure_garden + desired_residence + (1|class),
data = schools_prepost_test,REML = FALSE)

anova(fit3,fit4)

summary(fit4)


fit5<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age +
Family_primary_sector + Work_rural_nature + desired_residence + (1|class), data =
schools_prepost,REML = FALSE)

anova(fit4,fit5)

summary(fit5)


fit6<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age +
Family_primary_sector + desired_residence + (1|class), data = schools_prepost,REML =
FALSE)

anova(fit5,fit6)

schools_prepost_test<-schools_prepost%>%

  na.exclude(Work_rural_nature)

fit5<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age +
Family_primary_sector + Work_rural_nature + desired_residence + (1|class), data =
schools_prepost_test,REML = FALSE)

fit6<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age +
Family_primary_sector + desired_residence + (1|class), data = schools_prepost_test,REML =
FALSE)

anova(fit5,fit6)

summary(fit6)


fit7<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age  + desired_residence +
(1|class), data = schools_prepost,REML = FALSE)
```

```
anova(fit6,fit7)

summary(fit7)


fit8<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + desired_residence +
(1|class), data = schools_prepost,REML = FALSE)

anova(fit7,fit8)

schools_prepost_test<-schools_prepost%>%

  na.exclude(age)

fit7<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + age  + desired_residence +
(1|class), data = schools_prepost_test,REML = FALSE)

fit8<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment + desired_residence +
(1|class), data = schools_prepost_test,REML = FALSE)

anova(fit7,fit8)

summary(fit8)


fitfinaltransmission<-lmer(Post_TAeK_asum ~ 1 + Pre_TAeK_asum + Treatment +
desired_residence + (1|class), data = schools_prepost,REML = TRUE)

summary(fitfinaltransmission)

anova(fitfinaltransmission)

plot(fitfinaltransmission)

plot(allEffects(fitfinaltransmission))

ranef(fitfinaltransmission)
```

Appendix 4. Supplementary LMM outputs

4.1 Pre-intervention TAeK valuation index

```
Type III Analysis of Variance Table with Satterthwaite's method

                Sum Sq   Mean Sq   NumDF   DenDF   F value   Pr(>F)
age             98.034   98.034    1       168     8.6647    0.003704 **
leisure_garden  44.519   44.519    1       168     3.9348    0.048927 *
---
Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
```

Most parsimonious linear mixed model fit by REML (Pseudo . t-tests use Satterthwaite approximations to degrees of freedom [lmerMod]. Formula: Pre_TAeK_v_{sum} ~ 1 + age + leisure_garden + (1 | class). REML criterion at convergence: 899.4. Number of obs: 171, groups: class, 15

Fixed effects	Estimate	Std.Error	df	tvalue	Pr (>|t|)
(Intercept)	23.17114	1.10926	168. 0e+02	20.89	<2e-16***
age	0.14263	0.04723	168. 0e+02	3.02	0.00292**
leisure_garden_yes	1.14675	0.53340	168. 0e+02	2.15	0.03299*
Signif.codes:'***'0.001'**'0.01'*'0.05'.'0.1					
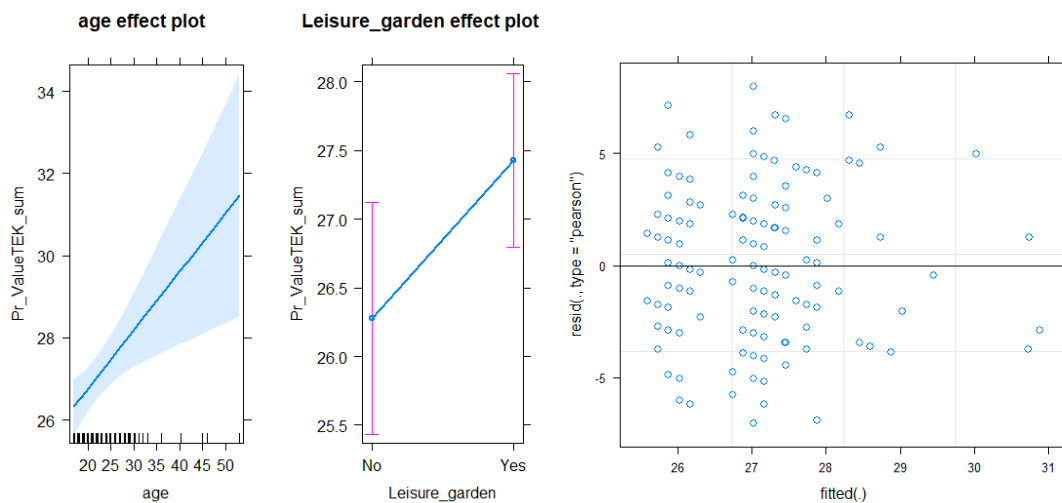
Correlation of Fixed Effects	(Intr)	Age
age	-0.923	
leisure_garden_yes	-0.294	-0.017

Random effects:

Groups	Name	Variance	Std.Dev.
class	(Intercept)	0.00	0.000
Residual		11.16	3.341

$class	(Intercept)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.10366	-0.67044	0.03481	0.61227	2.38627

4.2 Pre-intervention TAeK access index

```
Type III Analysis of Variance Table with Satterthwaite's method
                   Sum Sq  Mean Sq  NumDF DenDF  F value  Pr(>F)
program_theme      59.861   29.930    2    162   12.0204  1.357e-05 ***
desired_work       29.429    7.357    4    162    2.9547  0.0216912 *
Work_rural_nature  23.380   23.380    1    162    9.3896  0.0025568 **
Leisure_garden     34.102   34.102    1    162   13.6958  0.0002942 ***
---
Signif. codes:  '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
```

Most parsimonious linear mixed model fit by REML. t-tests use Satterthwaite's method [lmerM odLmerTest] Formula: Pre_TAeK_a$_{sum}$ ~ 1 + program_theme + desired_work + work_rural_nat ure + leisure_garden + (1 | class). REML criterion at convergence: 638.2. Number of obs: 171, g roups: class, 15

Fixed effects	Estimate	Std. Error	df	t value	Pr (>|t|)
(Intercept)	4.6797	0.3650	162.0000	12.819	<2e-16***
program_theme Conventional	-1.8879	0.3887	162.0000	-4.857	2.79e-06***
program_theme Environmental	-0.7877	0.3216	162.0000	-2.449	0.015397*
desired_work Conventional agriculture	-0.7932	0.3916	162.0000	-2.025	0.044475*
desired_work Environmental/forestry	-0.9946	0.3658	162.0000	-2.719	0.007264**
desired_work Other	-0.9092	0.4121	162.0000	-2.206	0.028776*
desired_work Gardening	-1.2757	0.4936	162.0000	-2.584	0.010639*
Work_rural_natureYes	0.7757	0.2532	162.0000	3.064	0.002557**
Leisure_gardenYes	0.9894	0.2673	162.0000	3.701	0.000294***
Signif.codes:'*'0.001'**'0.01'*'0.05'.'0.1**					
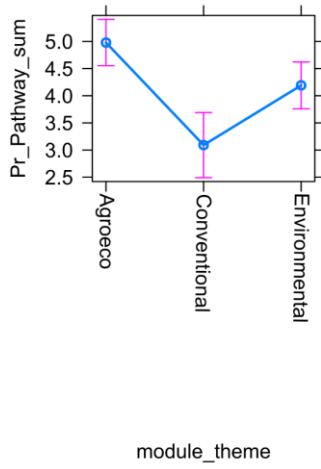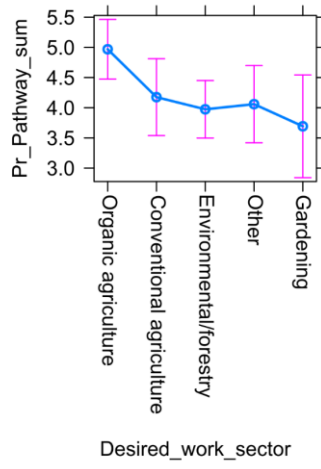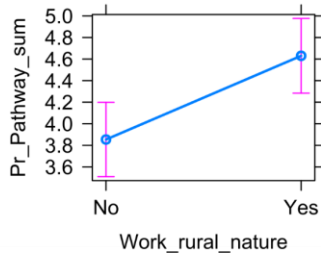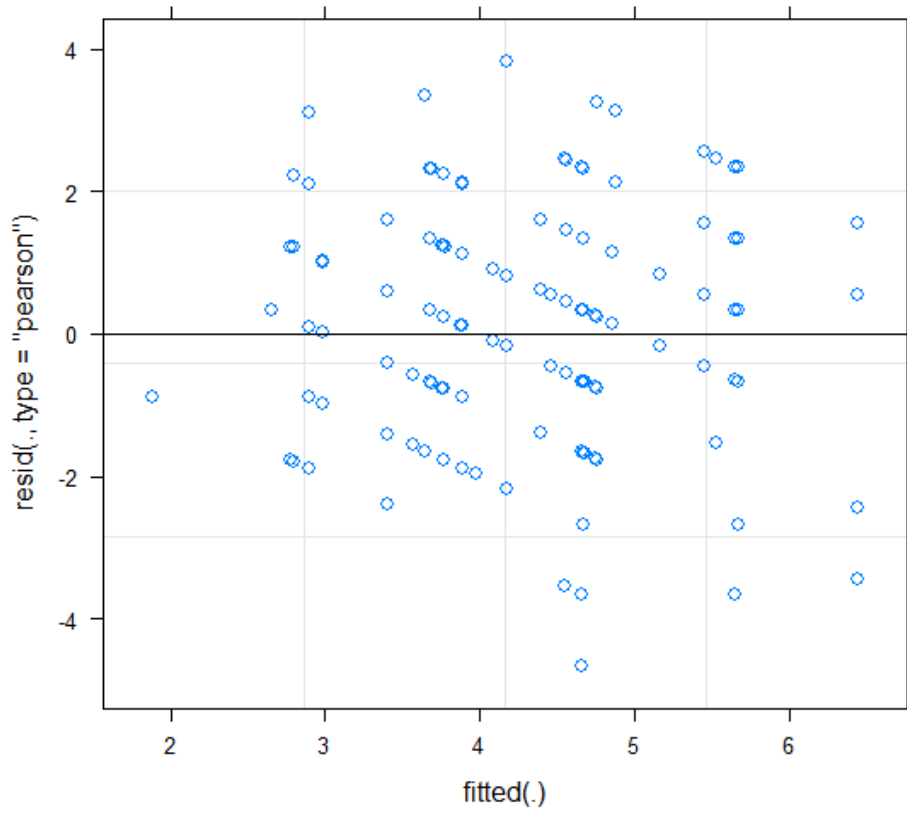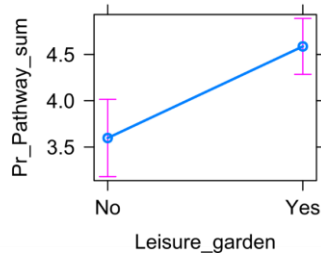
Correlation of Fixed Effects	(Intr)	pr_th Conv	pr_th Env	de_wo Conv	de_wo En/Fo	de_wo Oth	de_wo Gard	Work yes
program_theme Conventional	-0.414							
program_theme Environmental	-0.363	0.376						
desired_work Conventional	-0.225	-0.302	-0.102					
desired_work Environmental/forestry	-0.481	0.172	-0.332	0.344				
desired_work Other	-0.442	0.112	-0.086	0.328	0.477			
desired_work Gardening	-0.578	0.330	0.258	0.196	0.337	0.322		
Work_rural_nature_yes	-0.179	-0.199	-0.078	-0.025	0.026	-0.058	-0.074	
Leisure_garden-yes	-0.531	0.109	0.129	-0.104	0.057	0.086	0.208	-0.158

Random effects:

Groups	Name	Variance	Std.Dev.
class	(Intercept)	2.091e-16	1.446e-08
Residual		2.490e+00	1.578e+00

$`class`	(Intercept)
111	8.256586e-16
121	-3.729046e-16
212	2.607870e-16
321	-6.253195e-19
323	1.776277e-16
414	-3.423947e-17
422	-1.051437e-17
513	-3.831467e-16
521	-6.771615e-16
522	-8.892559e-17
621	-5.708907e-17
622	4.017261e-16
722	1.151000e-16
812	-4.384147e-16
911	2.821219e-16

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.9548	-0.5636	0.0650	0.6751	2.4210

4.3 Post intervention TAeK valuation index

```
Type III Analysis of Variance Table with Satterthwaite's method

              Sum Sq  MeanSq NumDF DenDF    Fvalue   Pr(>F)
Pre_TAeK_vsum 419.55  419.55 1     156.686  52.4136  1.897e-11 ***
treatment     36.15   18.08  2     10.105   2.2583   0.15463
gender_female 43.60   43.60  1     162.512  5.4467   0.02083 *
desired_work  110.28  27.57  4     136.310  3.4442   0.01025 *
---
Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
```

Most parsimonious linear mixed model fit by REML. t-tests use Satterthwaite's method [lmerM odLmerTest] Formula: $Post\_TAeK\_v_{sum}$ ~ 1 + $Pre\_TAeK\_v_{sum}$ + treatment + sex + desired_work + (1 | class). REML criterion at convergence: 843.6. Number of obs: 172, groups: class, 15

Fixed effects	Estimate	Std. Error	df	t value	Pr (>|t|)
(Intercept)	15.02391	1.88501	147.57539	7.970	3.97e-13***
$Pre\_TAeK\_v_{sum}$	0.44823	0.06416	157.32076	6.987	7.51e-11***
treatment_talk	1.87197	0.87023	14.53101	2.151	0.04873*
treatment_talk+practical	1.33078	0.79913	11.38433	1.665	0.12311
gender_female	-1.40591	0.61017	162.66098	-2.304	0.02248*
desired_work conventional agriculture	-2.32367	0.73306	148.06599	-3.170	0.00185**
desired_work environmental/forestry	-1.74521	0.63195	105.78336	-2.762	0.00678**
desired_work other	-1.70314	0.74548	162.04090	-2.285	0.02363*
desired_work gardening	-0.65308	0.86116	142.09345	-0.758	0.44948

Signif.codes:'*'0.001'**'0.01'*'0.05'.'0.1**

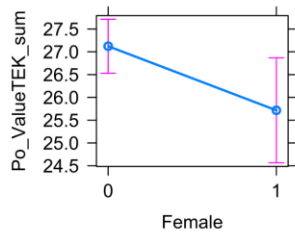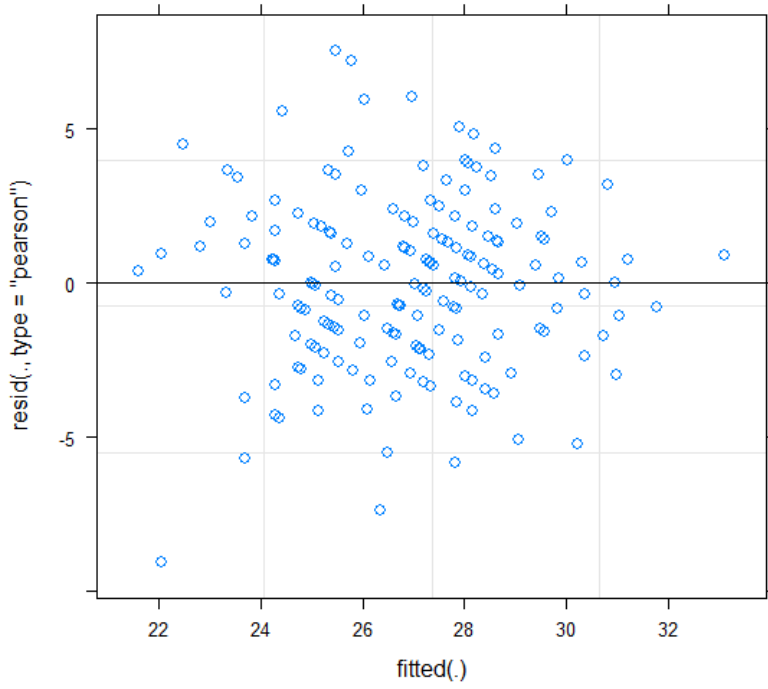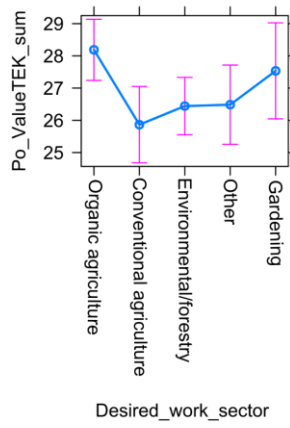## Pr_ValueTEK_sum effect plot
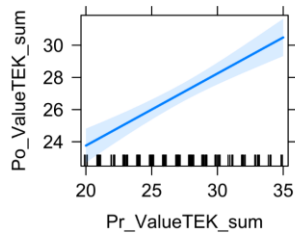
Treatment effect plot
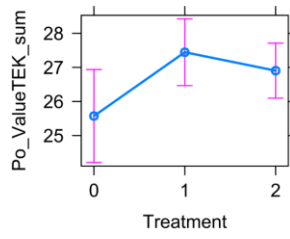
Female effect plot

Desired_work_sector effect plot

Correlation of Fixed Effects	(Intr)	P_T_V	t_T1	t_T2	gender _f	de_wo Conv	de_wo En/Fo	de_wo Oth
Pre_TAeK_v$_{sum}$	-0.904							
treatment_talk	-0.250	-0.062						
treatment_talk+practica	-0.270	-0.042	0.701					
gender_female	-0.038	-0.028	-0.077	-0.033				
desired_work conventional	-0.278	0.082	0.220	0.073	0.090			
desired_work environmental/forestry	-0.178	-0.006	-0.005	-0.024	0.190	0.443		
desired_work other	-0.086	-0.050	-0.022	-0.045	0.056	0.355	0.464	
desired_work gardening	-0.144	0.059	-0.083	-0.102	0.003	0.293	0.379	0.326

Random effects:

Groups	Name	Variance	Std.Dev.
class	(Intercept)	0.385	0.6205
Residual		8.162	2.8570

$`class`	(Intercept)
111	-0.25929371
121	-0.18875031
212	0.06592474
321	-0.31691860
323	0.02329777
414	-0.01780835
422	0.53278626
513	0.09213350
521	0.35799334
522	-0.22243075
621	0.22697386
622	-0.24330489
722	0.53288689
812	-0.51655586
911	-0.06693389

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.1658	-0.6160	0.0174	0.5666	2.6372

4.4 Post-intervention TAeK access index

```
Type III Analysis of Variance Table with Satterthwaite's method

                    Sum Sq  Mean Sq  NumDF DenDF F value  Pr(>F)
Pre_TAeK_asum       102.516 102.516  1     167   60.5018  7.233e-13
***
treatment           14.404  7.202    2     167   4.2503   0.015832 *
desired_residence   13.922  13.922   1     167   8.2162   0.004687 *
*
---
Signif. codes:  '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
```

Most parsimonious linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerM odLmerTest'] Formula: $Post\_TAeK\_a_{sum} \sim 1 + Pre\_TAeK\_a_{sum} + Treatment + desired\_residence + (1 \mid class)$. REML criterion at convergence: 583.6. Number of obs: 172, groups: class, 15

| Fixed effects	Estimate	Std. Error	df	t value	Pr (>|t|)
(Intercept)	1.39638	0.36485	167.00000	3.827	0.000183 ***
$Pre\_TAeK\_a_{sum}$	0.43624	0.05608	167.00000	7.778	7.23e-13 ***
treatment_talk	0.75799	0.31202	167.00000	2.429	0.016187 *
treatment_talk+practical	0.84278	0.29317	167.00000	2.875	0.004571 **
desired_residence_yes	0.65787	0.22951	167.00000	2.866	0.004687 **
Signif.codes:'*'0.001'**'0.01'*'0.05'.'0.1**					

Pr_Pathway_sum effect plot
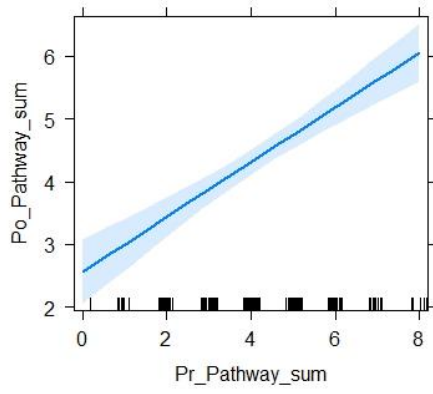
Treatment effect plot
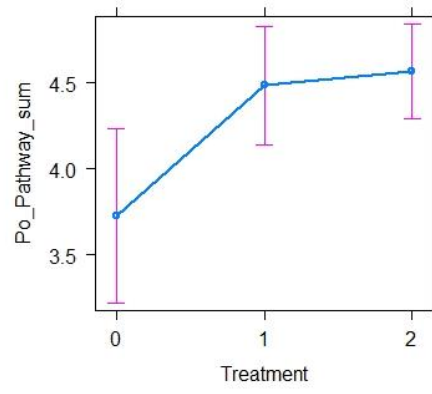
future_residence_rural effect plot
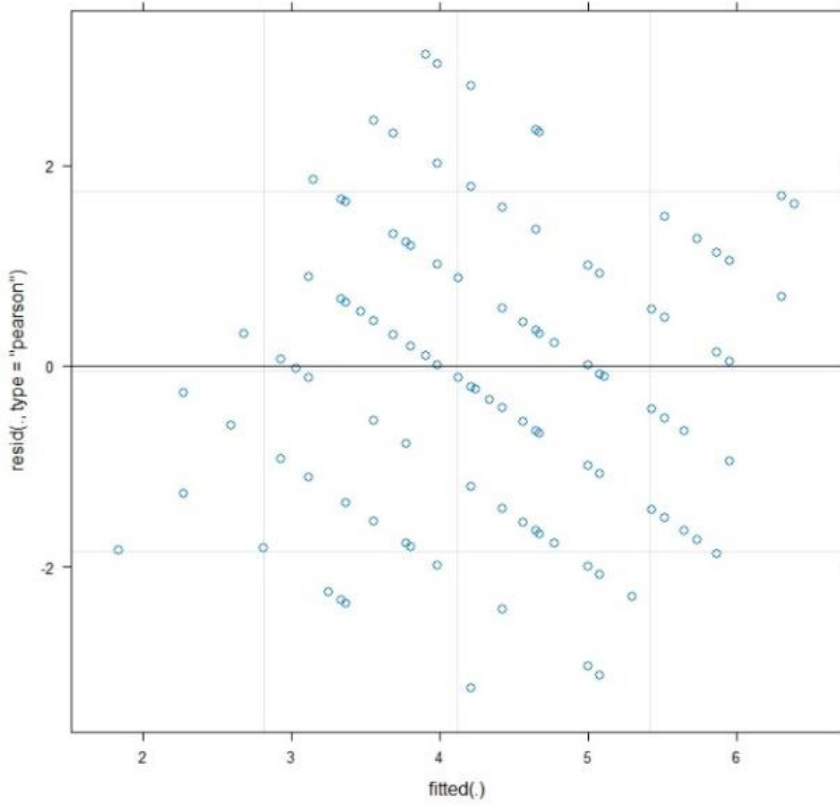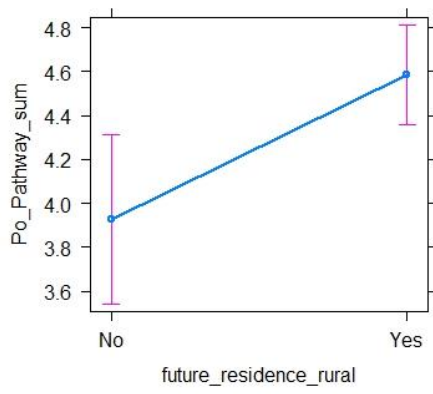
Correlation of Fixed Effects	(Intr)	Pre_TAeK_$_{Asum}$	treatment_T1	
Pre_TAeK_a$_{sum}$	-0.506			
treatment_talk	-0.490	-0.174		
treatment_talk+practical	-0.613	-0.090	0.729	
desired_residence_yes	-0.439	-0.121	0.032	0.108

Random effects:

Groups	Name	Variance	Std.Dev.
class	(Intercept)	0.000	0.000
Residual		1.694	1.302

$`class`	(Intercept)
111	0
121	0
212	0
321	0
323	0
414	0
422	0
513	0
521	0
522	0
621	0
622	0
722	0
812	0
911	0

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.46273	-0.62135	-0.02063	0.70814	2.38201