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Abstract

Background: The mental health crisis among college students intensified amid the COVID-19 pandemic, suggesting an urgent need for innovative solutions to support them. Previous efforts to address mental health concerns have been constrained, often due to the underutilization and/or shortage of services. Mobile health (mHealth) technology holds significant potential for providing resilience-building support and enhancing access to mental health care.

Objective: This study aimed to observe outcomes in health-related quality of life (HRQOL) among college students as the COVID-19 pandemic progressed over a three-year period, and whether the use of a positive psychology-based mHealth app (Roadmap app) was associated in these outcomes.

Methods: A longitudinal study was conducted remotely from a large public academic institution in the Midwestern United States, evaluating mental health and well-being outcomes among college students using the Roadmap mHealth app over three fall semesters from 2020 to 2022. The study enrolled 2,164 college students in Year I, with 1,128 and 1,033 students returning in Years II and III, respectively. Participants completed various self-reported measures, including PHQ-9 for depression, GAD-7 for anxiety, and additional metrics for coping, flourishing, and loneliness.

Results: Results indicated an evolving trajectory in students' mental health. Depression and anxiety levels were stable between Year I and Year II, later showing significant improvements by Year III (from Year I to Year III; P=0.005 and P=0.046, respectively). Problem-focused coping initially decreased from Year I to Year II (P<0.01), then increased between Years II and III (P=0.024), while emotion-focused and avoidant coping decreased continuously across all study years (from Year I to Year III; P<0.001 and P=0.02, respectively). Furthermore, decreases in loneliness (from Year I to Year III; P<0.001) were accompanied by increases in flourishing (from Year I to Year III; P<0.001). App usage analysis revealed that activities, such as Positive Piggy Bank and Gratitude Journal were most favored. Greater app engagement was positively correlated with enhanced flourishing, after adjusting for demographic and socio-behavioral characteristics (P=0.03).

Conclusions: Over the three years, students' mental health and well-being improved, with notable reductions in depression, anxiety, and loneliness, associated with an increase in flourishing. The Roadmap mHealth app did not appear to worsen mental health outcomes for students. Based on the usage pattern, it is possible the app enhanced positive psychology-based practices. Future research should explore the efficacy of similar mHealth interventions through randomized controlled trials to further

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Keywords: mHealth; mobile health; college student; mental health; positive psychology; flourishing; COVID-19; well-being; wellbeing

Introduction

Nearly 20 million students are enrolled in colleges across the U.S.[1] During this time, students undergo crucial psychological and social development.[2] Mental health issues are prevalent in college student populations, with the peak onset of mental illness occurring before age 25.[3] However, early detection of emerging mental illness before significant symptoms develop remains limited.[4] Without adequate attention, at-risk young adults with mental health issues are more likely to struggle academically (i.e., receive lower GPAs), drop out of college, or be unemployed compared to their peers.[5–7] These outcomes may consequently correlate with increased substance abuse, self-injury, and/or suicidality.[8–11]

The long-simmering mental health crisis in college students was further exacerbated by the COVID-19 pandemic, which saw higher levels of depression and anxiety than ever previously reported.[12,13] Even before the pandemic, the demand for mental health services was rising.[14,15] Thus, while the current mental health crisis among college students remains a major public health problem, it also presents a unique opportunity to develop and test novel interventions for providing psychosocial support to this population.

The increase in psychopathology across college campuses has led to expanded counseling and mental health services.[16,17] However, students who stopped attending college due to mental health concerns reported not seeking help or experiencing long wait times.[18] Alarmingly, 80% of students who die by suicide never contact their campus mental health services.[19] Both the underutilization and shortage of mental health services are significant issues.[20,21] Mobile health (mHealth) technology offers a novel approach to overcoming barriers associated with mental health care delivery.[22] Evidence suggests that mHealth interventions can support various mental health problems, such as mood disorders, stress, and substance use.[23,24] Focusing on resilience-building aligns with with recent recommendations that mental health-related mHealth apps should support well-being, enhance mood, and foster self-care skills rather than addressing specific mental health problems.[25] Mobile health technology has been shown to be convenient, anonymous, and easy-to-use.[26]

Our interdisciplinary team developed a positive psychology-based mHealth app, *Roadmap*, initially for use in patients with cancer and their family caregivers. It was designed to provide information, education, and skills-based training. Over time, it was iteratively enhanced to support the physical, mental, and social health-related quality of life (HRQOL) of *any* user and to aggregate their step counts and sleep, collected through wearable sensors (Fitbits®).[27]

In the fall semester of 2020, we leveraged the Roadmap app to explore HRQOL outcomes among college students.[28] Approximately one-third of students had a mental health disorder and given the strict lockdown restrictions in the fall semester of 2020, students recorded low physical activity levels (via Fitbits®). Additionally, we found significant associations of COVID-19 positivity with the use of marijuana and alcohol and with lower belief in public health measures.[29] With consent, the same students were invited to participate in the Roadmap study and report their HRQOL in the following fall semesters of 2021 and 2022. Based on our initial observations[28] and the emerging literature on college student mental health during the pandemic,[30] we posited that our

participants would report changes in their HRQOL as the pandemic progressed, specifically across the three-year study period. We also explored whether the Roadmap app, a positive psychology-based mHealth app, might be associated with changes in these HRQOL outcomes. By examining both the trajectory of HRQOL and the role of the Roadmap app, our work contributes to understanding the broader effects of the pandemic on student mental health and highlights the potential of an mHealth app in supporting psychological well-being.

Methods

Ethical Statement

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of the University of Michigan Medical School (IRBMED) and was registered on ClinicalTrials.gov (NCT04766788). Study participants completed an IRB-approved informed consent through the SignNow platform (www.signNow.com). The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Study Site

The study took place at a large public academic institution in the Midwestern United States. For the safety of participants and staff during the pandemic, study activities were conducted entirely remotely, with study materials shipped to participants' residences. This was a 3-phase study conducted in the fall semesters of 2020, 2021, and 2022, referred to as Year I, Year II, and Year III, respectively. Notably, the same cohort of students was invited to participate each year, beginning from Year I, aside from any participants who had formally dropped out.

Recruitment and Enrollment

The research protocol was previously published,[28] and additional information regarding the

study design for Year I can be found in our prior manuscript.[29] *Briefly*, eligible participants were required to be college students of at least 18 years of age. Additional eligibility requirements included having access to the necessary resources for participating in an mHealth technology-based intervention (i.e., smartphone/tablet and internet access), and being willing to use their personal equipment and internet for the study.

We recruited the Year I cohort of students in the fall semester of 2020 through an email distribution channel managed by the institution and approved by the IRB; this email list initially reached all currently registered and enrolled college students in 2020. Additionally, we distributed flyers throughout campus buildings and buses. Interested participants were provided with additional study information, including an overview of study procedures, risks, benefits. If they met the eligibility criteria, participants were given a digital IRB-approved informed consent form. In Year I, 2164 participants enrolled in the study. For Year II and Year III, these students were re-contacted in the respective fall semester to complete HRQOL surveys.

Study Procedures

Roadmap and Fitbit® Apps: In Year I, participants were instructed to download the Roadmap and Fitbit® apps to their smartphones (both free of charge and available on Apple and Google app stores). The Roadmap app offered eight resilience-based positive activities, previously described in Rozwadowski et al,[27] and provided in **Multimedia Appendix I**. Participants could also engage with each other anonymously via a *Chat Forum* (i.e., peer-to-peer support) on each of these topics. Participants were instructed to use these activities as much or as little as they found helpful. Additionally, participants were asked to record their daily mood on a scale of 1 to 10 (1 being the worst and 10 being the best), with a reminder sent via push notification to their smartphones at 8:00pm. In Year II, participants had the option to continue using the Roadmap activities and monitor their physical activity and sleep with Fitbits®. In Year III, participants did not have access to the

Roadmap activities.

Self-Reported Assessments: Participant self-reported HRQOL assessments through the Roadmap app. The Roadmap app provides a link to Qualtrics (Qualtrics, Provo, UT) which hosts study-specific surveys and the secure storage of participant data. We connected participant surveys together using a unique ID associated with the Roadmap app, rather than any personally identifiable information. The survey data collected during Year I, Year II, and Year III were used in this study's analysis. In Year I and Year II, the survey intervals included baseline, Month 1, Month 2, and Month 3; in Year III, the survey was collected only at baseline. At the appropriate intervals, leveraging both Roadmap app reminders and study team emails, we prompted participants to complete each survey and provided compensation for each completed survey. Surveys were scored in accordance with their standardized scoring and as previously published.[29]

1. *Coping*: We used the 28-item Brief COPE,[31] which assesses the self-reported frequency of use of 14 different coping strategies to deal with a particular situationally specific life event, including self-distraction, active coping, denial, alcohol and drug use, use of emotional support, use of instrumental support, behavioral disengagement, venting, positive framing, planning the use of humor, acceptance, and religion. The current study's analysis followed the subscale analyses provided in Poulus et al 2020.[32]
2. *Flourishing*: A 10-item measure with 2-items each in the following categories: 1) happiness and life satisfaction; 2) mental and physical health; 3) meaning and purpose; 4) character and virtue; and 5) close social relationships. A higher score indicates greater flourishing.[33]
3. *Loneliness*: A 3-item measure assessing isolation, feeling left out, or lacking companionship. A higher score is associated with increased loneliness.[34,35]
4. *Anxiety.* We used the Generalized Anxiety Disorder (GAD-7), a 7-item anxiety assessment commonly used in primary care. Scale scores are categorized into minimal, mild, moderate,

and severe anxiety. An increased score is associated with increased anxiety. Previous studies found an internal consistency of 0.89.[36]

5. *Depression.* We used the Patient Health Questionnaire (PHQ-9), a 9-item depression assessment commonly used in primary care. Scale scores are categorized into minimal, mild, moderate, moderately-severe, and severe depression. An increased score is corresponding to increased depression. Previous studies have reported an internal consistency of 0.83–0.92.[37]

Statistical analysis

We conducted longitudinal analyses of data from the 3-phases, encompassing 2164 students in Year I, with 1128 students returning in Year II, and 1033 students returning in Year III. Descriptive statistics were compiled for categorical variables in terms of frequency and percentage, while continuous variables were summarized using the mean, standard deviation (SD), median, and interquartile range (IQR). Boxplots were used to depict the median and overall distribution of key measures. Univariate associations between continuous and demographic variables were evaluated. Depending on data normality (assessed with the Shapiro-Wilk test[38]), continuous variables were compared across two categorical variable levels using either two-sided T-tests or Wilcoxon rank-sum tests. For comparisons across three or more levels of categorical variables, ANOVA or Kruskal-Wallis tests[39] were employed. Associations between two categorical variables were examined using the Chi-squared test,[40] leveraging the relatively large sample size. To assess associations between continuous variables, two-sided Pearson's or Spearman's correlations[41] were calculated based on data normality. Paired t-tests were utilized to evaluate inter-year differences in outcome means. Correlation coefficient matrices were constructed to illustrate the relationships among continuous outcomes. Missing values for continuous variables, including PHQ-9 and GAD-7 scores, were imputed using Multiple Imputation by Chained Equation (MICE)[42] with Predictive Mean Matching. The app use variable was computed as the sum of the frequencies of positive activities, chat forum

interactions, and mood entries. All tests were at a significance level of 0.05. All analyses were performed using statistical software R (version 4.2.3).

A directed acyclic graph (DAG) was postulated to relate the key variables of flourishing, depression (PHQ-9 score), anxiety (GAD-7 score), and loneliness in the context of pandemic time. Based on this DAG, separate regression models were specified for flourishing, anxiety, and depression as outcomes. These models considered only baseline data, modeling the current year's baseline response in Year II and Year III on the previous year's baseline explanatory variables. We also conducted a formal mediation analysis based on this DAG.

We separately considered the monthly responses for flourishing in Year I and Year II. These analyses utilized a total of six assessments, given in consecutive months, modeling current month's flourishing for months 2, 3, and 4 on the previous month's explanatory variables, including app usage.

All models included time-invariant fixed effects for time since pandemic peak (year), sex, undergraduate/graduate status, coping scores, and drug use. To account for within-subject dependence, random intercepts and slopes (year) at the participant-level were included.

Results

Student Demographics

Of the 2,164 students who participated in Year I, 1,128 returned in Year II, and 1,033 returned in Year III. Notably, 755 students participated in all three years (**Figure 1**). The majority of participants in Year I were White (n=1243; 57%), female (n=1467; 68%), and undergraduates (n=1429; 66%). The demographic characteristics remained largely consistent across time, with the exceptions of an increase in those who reported no longer being students and a higher proportion of

females (**Table 1**).

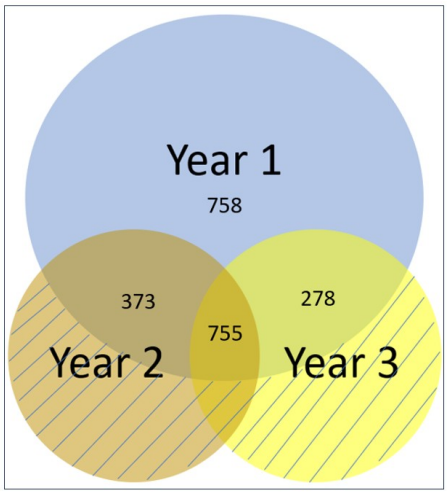

Figure 1. Venn Diagram of Student Participation Across the 3-Year Study Period. Year I: n=2164; Year II: n=1128; and Year III: n=1033. N=755 students participated in all 3-phases; n=373 were unique to Year I and Year II; and n=278 participants were unique to Year I and Year III.

Table 1. Demographic Breakdown of Study Participants over Three Years

Participant Demographics (*population, n %*)				
Demographics	Year I	Year II	Year III	*P* value[a]
School year				<0.001
Undergraduate	1429 (66.04)	544 (48.23)	338 (32.72)	
Graduate	719 (33.22)	363 (32.19)	269 (26.04)	
No longer a student	15 (0.69)	218 (19.32)	426 (41.24)	
N/A	1 (0.05)	3 (0.27)	0 (0.00)	
Gender				0.004
Female	1467 (67.80)	833 (73.87)	740 (71.64)	
Male	677 (31.28)	283 (25.09)	283 (27.40)	
Other	11 (0.51)	11 (0.98)	9 (0.87)	
N/A	9 (0.42)	1 (0.09)	1 (0.10)	
Race				0.92
White	1243 (57.44)	643 (57.03)	604 (58.48)	
Black or African American	94 (4.34)	40 (3.55)	40 (3.87)	
Asian	652 (30.13)	356 (31.56)	309 (29.91)	
Multiracial	113 (5.22)	62 (5.50)	55 (5.32)	
Other	39 (1.80)	18 (1.60)	18 (1.74)	
N/A	23 (1.06)	9 (0.80)	7 (0.68)	

Ethnicity				0.17
Hispanic or Latino	210 (9.70)	94 (8.33)	81 (7.9)	
Non-Hispanic or Latino	1949 (90.04)	1029 (91.60)	947 (92.1)	
N/A	5 (0.23)	5 (0.44)	5 (0.48)	
Domestic or International				0.36
Domestic	1996 (92.24)	1027 (91.05)	957 (92.63)	
International	163 (7.53)	98 (8.7)	74 (7.16)	
N/A	5 (0.23)	3 (0.27)	2 (0.19)	
First or continuing generation				0.83
First generation	541 (25.00)	290 (25.71)	254 (24.59)	
Continuing generation	1617 (74.74)	834 (73.94)	775 (75.01)	
N/A	6 (0.28)	4 (0.35)	4 (0.39)	

a*P* values are representative of a chi-square test performed for the entire study population.

Student Coping Skills

We examined student coping skills over the three-year study period using pairwise comparisons between each pair of years, restricted to students who responded in both years. While *problem-focused coping* decreased from Year I to Year II ($P<0.01$), it remained stable between Year I and Year III ($P=0.23$), but increased from Year II to Year III ($P=0.024$; **Figure 2A**). *Emotion-focused coping* decreased from Year I to Year II ($P<0.001$) and from Year I to Year III ($P<0.001$), but remained stable between Year II and Year III ($P=0.65$; **Figure 2B**). *Avoidant coping* decreased across all timepoints, including from Year I to Year II ($P<0.001$), Year I to Year III ($P=0.02$), and Year II to Year III ($P=0.018$; **FIgure 2C**).

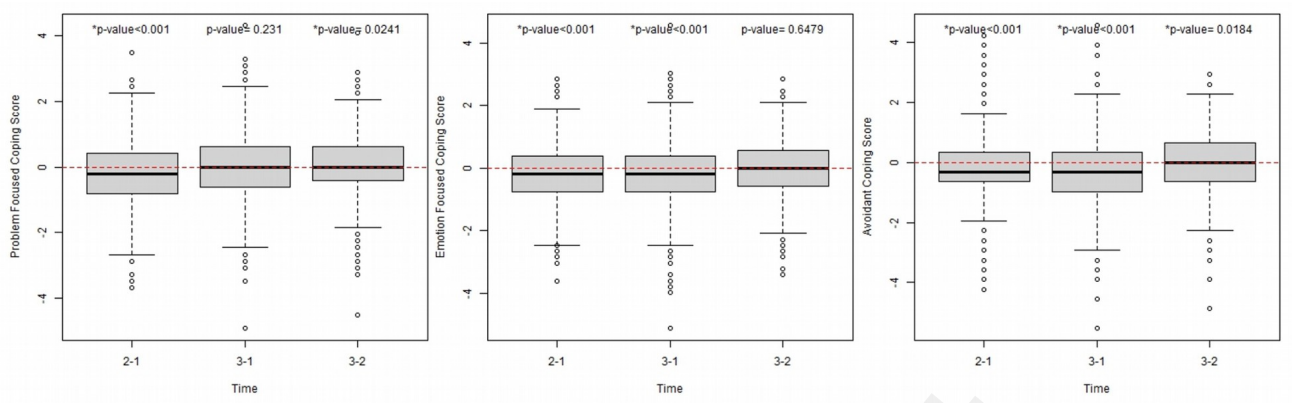

Figure 2. Coping Skills Across the 3-Year Study Period. The boxes in each plot depict differences between pairs of phases. Panels (a)-(c) illustrate problem-focused, emotion-focused, and avoidant coping, respectively.

Student Mental Health and Well-Being Outcomes

Next, we examined self-reported outcomes of depression (PHQ-9), anxiety (GAD-7), loneliness, and flourishing. While there was no change in average depression (**Figure 3A**) and anxiety symptoms (**Figure 3B**) between Year I and Year II, both significantly declined from Year I to Year III (P=0.005 and P=0.046, respectively) and from Year II to Year III (P<0.001 and P<0.001, respectively).

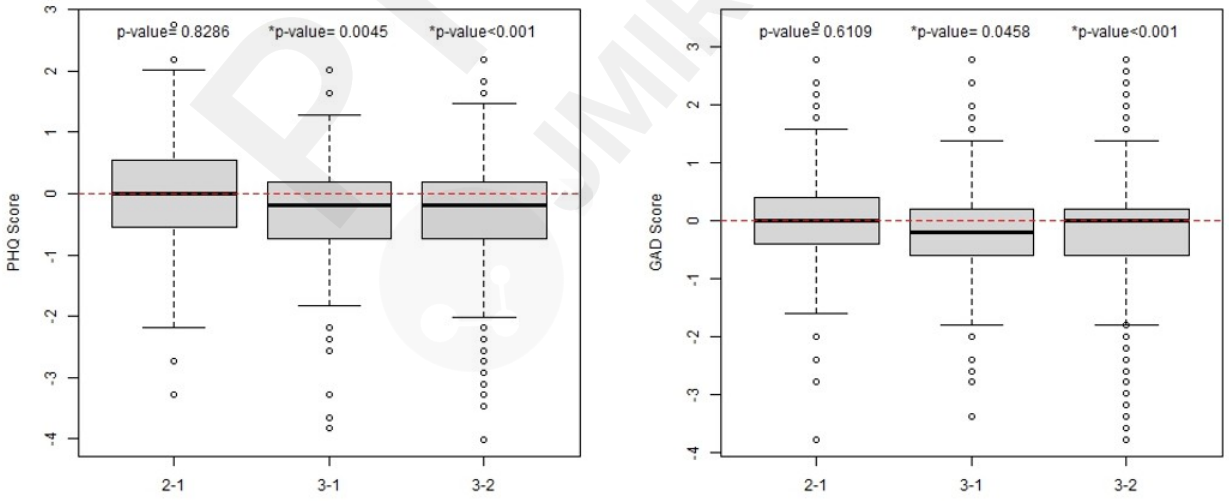

Figure 3. Depression (PHQ-9) and Anxiety (GAD-7) Across the 3-Year Study Period

Average reported loneliness scores decreased significantly over the three study years (P<0.001 across all pairwise comparisons; **Figure 4A**). This correlated with increased average flourishing from

Year I to Year III (P<0.001) and from Year II to Year III (P<0.001; **Figure 4B**).

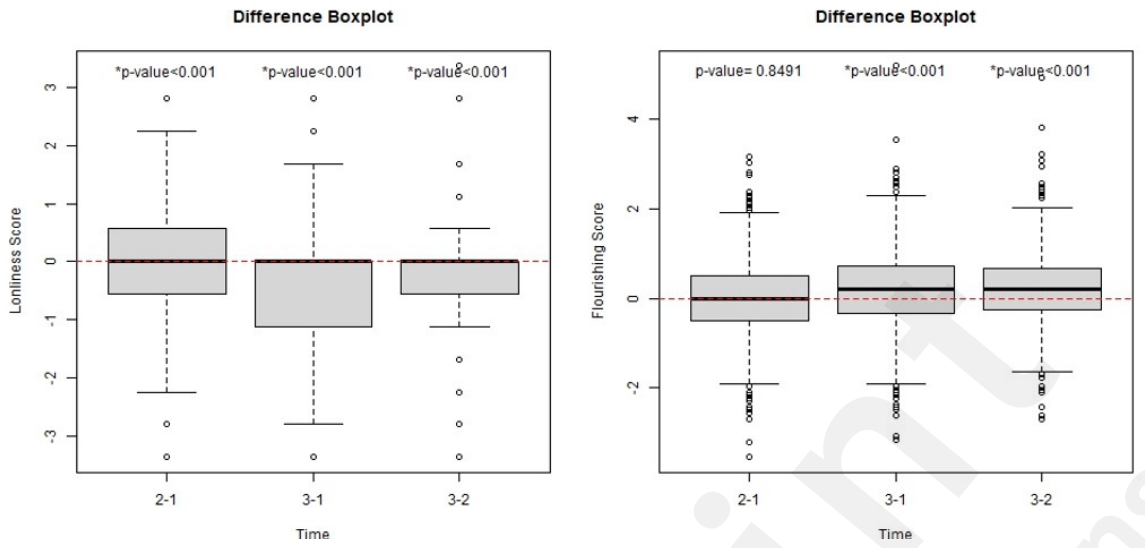

Figure 4. Flourishing and Loneliness Across the 3-Year Study Period

Impact of Pandemic Recovery on Student Flourishing

We explored potential pathways to better understand the factors that may be contributing to changes in students' flourishing over time using a series of multilevel regression analyses guided by a directed acyclic graph (DAG; **Figure 5**). We found that students' flourishing improved significantly with time from the peak of the pandemic (β=0.128). This improvement was partially influenced by loneliness and depression. That is, in any given year, students with more loneliness and/or more depression had lower flourishing (β=-0.169 and -0.071 respectively), while average loneliness, anxiety, and depression also decreased with the passage of time (β=-0.127, -0.229, -0.145 respectively). While a formal mediation analysis confirmed the mediating role of loneliness on flourishing, anxiety and depression were not significant mediators of the relationship between pandemic year/severity and flourishing (see **Multimedia Appendix II**).

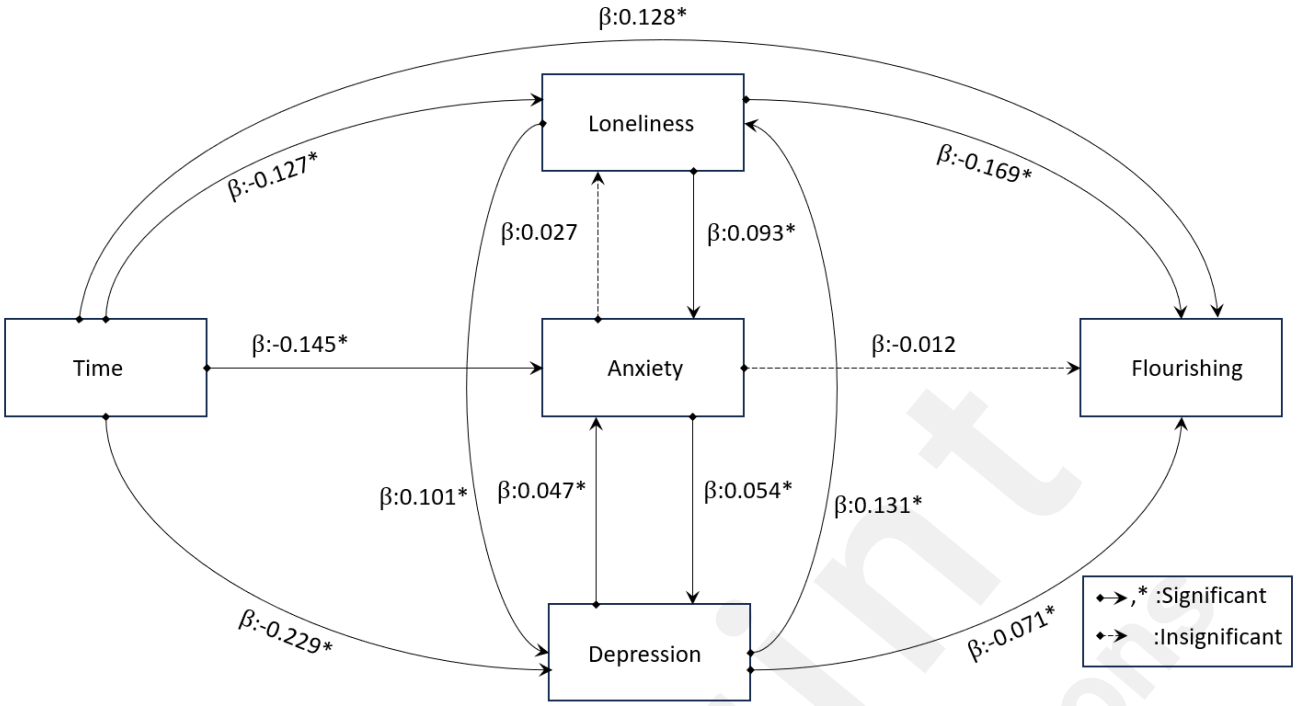

Figure 5. Potential Pathways Influencing Student Flourishing. We summarize the multilevel models where the endpoints of the arrows represent the outcomes and the starting points indicate the predictors. All predictors in the models are lagged by one year, allowing them to forecast the outcomes in the subsequent year. Solid lines with star symbols denote significant p-values, while dashed lines indicate non-significant p-values. The symbol represents the estimated value in the respective model.

App Use

Next, we examined student app usage patterns over the study period. As shown in the UpSet Plot (**Figure 6**), the two most frequently used activities were Positive Piggy Bank and Gratitude Journal, followed by Pleasant Activity Scheduling, Savoring, and Engaging with Beauty. The least favored activities were Love Letter, Signature Strengths, and Random Acts of Kindness.

Single activity usage was the most common (i.e., only used that activity and none of the others within a ‘single’ session of using the app), but notable combinations included students who used both Positive Piggy Bank and Gratitude Journaling. Smaller intersections included combinations, such as (i) Pleasant Activity Scheduling and Gratitude Journal; (ii) Engaging with Beauty and Gratitude Journal and Positive Piggy Bank; and (iii) Savoring, Gratitude Journal, and Positive Piggy Bank.

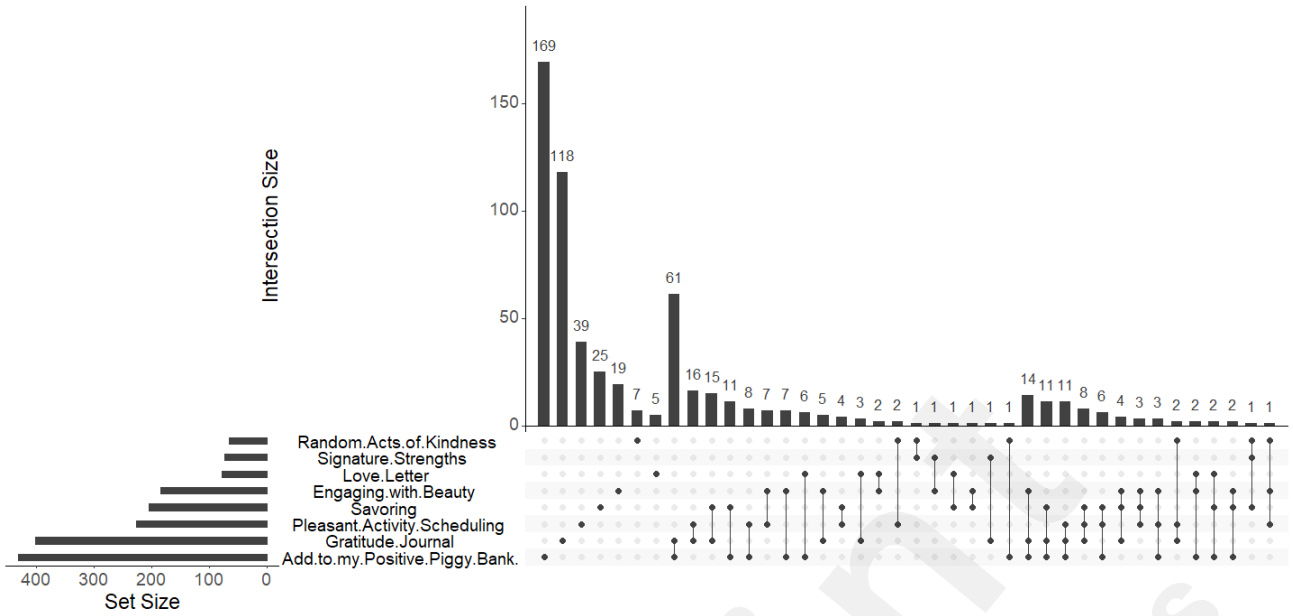

Figure 6: UpSet Plot for Activity Engagement Patterns In Year 1 and Year 2. This UpSet plot visualizes the intersection of the positive activities engaged by students using the app in Year 1 and Year 2. The x-axis represents unique combinations of activities, while the y-axis indicates the number of users for each combination. Of note, single app usage is represented by the Set Size on the left: “Positive Piggy Bank" (431 unique users) and "Gratitude Journal" (402 unique users). Other activities included "Pleasant Activity Scheduling" (227 users), "Savoring" (205 users), and "Engaging with Beauty" (184 users). "Love Letter" (78 users) and "Signature Strengths" (74 users) had moderate engagement, while "Random Acts of Kindness" (66 users) was the least used.

Based on the above findings, we were interested in determining whether app use correlated with improved flourishing in the subsequent month. After adjusting for demographic and socio-behavioral characteristics, more frequent app use was associated with greater flourishing (P=0.03). For example, implied by **Table 2**, 30 instances of app use was associated with a nearly one-unit increase on the flourishing scale.

Table 2: Fixed Effects Results from Mixed Effects Model

Variables	Estimate	*P value*
Problem Focused Coping Lagged	3.062	<0.001 ***
Emotion Focused Coping Lagged	-0.870	0.080 .
Avoidant Coping Lagged	-1.843	<0.001 ***
PHQ Score Lagged	-0.213	<0.001 ***
GAD Score Lagged	-1.151	<0.001 ***
Loneliness Score Lagged	-1.483	<0.001 ***

Age	0.051	0.384
App Usage	0.035	0.03 *
School Year		
Undergraduate	-ref	-ref
Graduate	1.726	<0.001 ***
No longer a student	1.090	0.162
Gender		
Female	-ref	-ref
Male	0.470	0.375
Other	0.533	0.844
Ethnicity		
No	-ref	-ref
Yes	1.262	0.175
International Status		
Domestic	-ref	-ref
International	2.451	0.011 *
Generation		
Continuing Generation	-ref	-ref
First Generation	-1.025	0.070 .
Tobacco History		
No	-ref	-ref
Yes	0.086	0.911
Marijuana History		
No	-ref	-ref
Yes	-0.646	0.177
Vaping History		
No	-ref	-ref
Yes	-0.683	0.208
Alcohol History		
No	-ref	-ref
Yes	0.020	0.971
COVID Diagnosis		
No	-ref	-ref
Yes	-0.115	0.928
Mental Condition		
No	-ref	-ref
Yes	-4.724	<0.001 ***
Race		
White	-ref	-ref
Asian	-3.167	<0.001 ***
Black	-2.752	0.024 *
AIAN	6.892	0.205
Multi	-0.967	0.365

Other	-1.121	0.560
Year		
2020	-ref	-ref
2021	1.941	<0.001
Month		
October	-ref	-ref
November	0.820	0.005 **
December	0.500	0.101

This table presents the estimates and p-values for the fixed effects in the mixed effects model. “-ref” represents the reference category for the corresponding variable. Significance is indicated with stars: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

Discussion

Principal Findings

Building on our prior work,[28,29] the initial cohort of college students from the 2020 mHealth Roadmap Study were invited to participate in two subsequent semesters in the fall of 2021 and 2022. Leveraging the use of mHealth technology, we longitudinally followed their mental health and well-being outcomes, during a historically unprecedented period marked by ongoing global challenges.[13] One of the principal findings from this study is the reporting of sustained, yet evolving, mental health challenges among college students over the three years. Depression and anxiety levels remained consistent between Year I and Year II (2020–2021), but showed significant improvements by Year III (2022). This trend suggests a potential period of initial adjustments to the pandemic’s disruptions, followed by gradual mental health recovery as students adapted to the new norms and reduced pandemic-related stressors. Prior to vaccination, students experienced a multitude of changes related to pandemic restrictions, including lockdowns and stay-at-home orders, remote learning mandates, travel bans, social distancing measures, mask mandates, and closure of non-essential businesses.[43]

Similarly, we also observed changes in student coping strategies over time. Problem-focused coping initially decreased but then increased between Year II and Year III. Emotion-focused coping consistently decreased from Year I, while avoidant coping showed a steady decline across all time

points. These adaptive shifts suggest that students may have developed new strategies to manage themselves. It is possible that the type of coping strategy employed may influence mental health outcomes, as previously discussed.[44] A notable and encouraging finding in this study was the significant decrease in reported feelings of loneliness, which was associated with increases in flourishing across the study period. This suggests that students may have re-established social connections, possibly through remote platforms initially, mHealth technology, and later in-person interactions as restrictions eased.

Students engaged with the Roadmap app with strong preference for activities focusing on personal reflection, such as Positive Piggy Bank and Gratitude Journal. Our findings suggest that app use may have positively impacted flourishing, which correlated with increased problem-focused coping and reduced avoidant coping. Reduced levels of depression, anxiety, and loneliness may have also played key roles.

Possible Mechanisms

Counter to what we initially posited that mental health outcomes and well-being would worsen over the three-year study period, our study revealed that even amid the challenges posed by the pandemic, students reported significant improvements in flourishing over the three-year period. Flourishing, a term that encapsulates functioning in a manner conducive to growth, resilience, and overall goodness, provides key insights into mental health viewed in a positive manner.[45] This concept aligns with aspects of well-being, including elements such as purpose in life, meaningful relationships, and optimism. Thus, we sought to understand possible mechanisms explaining the link between time from pandemic severity, depression, anxiety, loneliness, and flourishing.

Our data showed that the passage of time from the peak of the pandemic corresponded with higher levels of flourishing. Furthermore, this increased duration was also associated with decreased feelings of loneliness, anxiety, and depression. An increase in flourishing was partially influenced by lower levels of loneliness and depression in the regression model. Interestingly, the mediation

analysis only supported the role of loneliness partially mediating increased flourishing, whereas anxiety and depression did not significantly impact the relationship between time since the pandemic's peak and flourishing. While anxiety had a direct negative effect on depression, anxiety did not influence loneliness. These findings align with ongoing debates about the causal relationships and comorbidity between anxiety and depression,[46] as well as their interplay with loneliness.[47] Accordingly, there may be additional factors between loneliness and the constructs of anxiety and depression that were not captured by the present study.

Our findings suggest that the time elapsed since early days of the pandemic may have directly influenced students' flourishing, possibly due to reasons, such as increased rates of vaccination, increased opportunities for social interaction with lifts on social restrictions and mask mandates, and return to in-person classroom settings. It is also possible that app use may have contributed to some of our observations when students had access to the Roadmap's positive activities in Year I and Year II of the study. During the early period of social restrictions, mHealth technology may have offered an avenue for students to re-establish social connections and practice simple strategies through well-studied constructs, such as positive daily reflection, gratitude, and savoring.

Comparison with Previous Studies

Previous studies have shown that emotion-focused coping (e.g., acceptance, religion, and social support) is associated with improved psychological adjustment, while avoidant coping is linked with increased distress. Problem-focused coping is less utilized in unpredictable events,[48,49] but correlates with positive outcomes.[50] Early in the pandemic, studies indicate that students primarily used emotion-focused coping strategies.[49,51,52] Contrary to these findings, our study participants reported decreased use of *problem-focused, emotion-focused,* and *avoidant* coping strategies in the pandemic year (2020). This decline may reflect the widespread use of disengagement strategies at the pandemic's peak. Over time, students in our study reported a decline in avoidant coping with changes in problem-focused and emotion-focused coping, aligning with

other recent pandemic-related studies.[49,51,52]

The coping patterns observed herein correlated with an overall decline in depression and anxiety symptoms across each subsequent year of the study. Studies have shown varied findings regarding student psychological distress during the pandemic, with some reporting positive self-efficacy in online learning.[53] However, during the same period (2020–2022), a large national survey of college student mental health (Healthy Minds Network) reported increases in the percentages of students with elevated depression and anxiety scores (PHQ-9: 18% to 23%; and GAD-7: 31% to 37%, respectively).[54] Although we acknowledge differences in participant pools–our study followed the same cohort across the three years, while the Healthy Minds Network recruits new students annually–a notable difference is that our students had access to a positive psychology-based mHealth app (Roadmap). In contrast, to our knowledge, access to mHealth app support in the Healthy Minds Network population is not known.

Students who engaged with the Roadmap app favored activities that focused on personal reflection and mindfulness (i.e., inward-facing), such as the Positive Piggy Bank and Gratitude Journal. A recent study showed that mindfulness meditation delivered via mHealth was an approach used by college students to reduce stress and improve mindfulness and self-compassion.[55] Interestingly, we observed lower engagement in activities, such as Random Acts of Kindness or Love Letter, which involved interaction with others or had an external focus (i.e., “outward-facing”). It is possible this may have been due to social distancing constraints and the complexity of coordination such actions during the pandemic.

Public Health Impact

The literature suggests that the pandemic may have exacerbated mental health challenges among college students, a population already experiencing increased reports of anxiety, depression, and stress. The experience of social isolation, particularly during a crucial period of social interactions and development growth as emerging adults, may have led to poorer management of

other aspects of well-being. Understanding these trends and identifying groups with increased prevalence are crucial for developing novel approaches to mental health care aimed at effectively addressing these issues. To mitigate these challenges, the adoption of novel mHealth technologies through smartphone apps has significantly accelerated over the past several years.[56] Such technologies, as leveraged in this study, hold great potential to fundamentally address mental health challenges, particularly in college students.[57]

Limitations

This study had several limitations. Students self-selected to be in this study, which was meant to focus on positive psychology-based strategies to enhance mental health. It relied on self-report surveys to collect information about mental health and well-being and the majority of participants were female. Approximately one-third of the initial participants did not take part in subsequent years of the study (i.e., lost to follow-up). Additionally, as we followed students over the course of three years, some graduated and were no longer on campus, potentially reducing their access to college resources. It is important to note that our findings are specific to students from a single Midwestern location and may not be generalizable to other regions or student populations. For example, certain demographic groups might be underrepresented or overrepresented due to the college's location in the Midwest. We did not collect data on participants' ongoing or concurrent mental health treatments or medications. Finally, we acknowledge the lack of a fully powered, randomized controlled trial design. Despite these limitations, this study constitutes a large-scale, longitudinal study conducted during an unprecedented time, providing valuable insights into the mental health challenges of college students.

Conclusions

This longitudinal study of college students observed a decline in average loneliness, depression, and anxiety with increasing time from pandemic peak that coincided with increased

flourishing. This increased flourishing was partially, but not fully explained by improved loneliness, anxiety, and depression. Students had access to a positive psychology-based app and used variable coping strategies during the study. Future research should examine the efficacy of the Roadmap app through a randomized controlled trial, utilizing a robust study design to assess its impact on mental health outcomes.

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Authors' Contributions

GJ drafted the manuscript and curated the data and figures; this was part of his University of Michigan Honors Thesis project. MR coordinated the study, carried out recruitment, provided consent, carried out onboarding, curated the data and figures, and critically reviewed and edited the manuscript. GJ and SWC performed the background literature review, visualized the data, and critically edited and revised the manuscript. AH provided expertise in psychometric analyses, data interpretation, data visualization, and critically edited and revised the manuscript. XC cleaned and processed the data, analyzed the data, curated the data and figures, and critically reviewed and edited the manuscript. KS supervised the statistical analysis and data interpretation, and critically reviewed

and edited the manuscript. MT and SWC envisioned and designed the study, procured resources, supervised the study, interpreted data, and helped draft, edit and critically revise the manuscript. SWC created the Roadmap app.

Data Availability

Data are available on request. The study protocol and statistical code can be obtained from SWC and XC. The data set is available from the University of Michigan through a data use agreement.

Abbreviations

HRQOL: Health related quality of life

GAD-7: Generalized Anxiety Disorder-7

PHQ-9: Patient Health Questionnaire-9

SD: Standard deviation

IQR: Interquartile range

MICE: Multiple Imputation by Chained Equation

DAG: Directed acyclic graph

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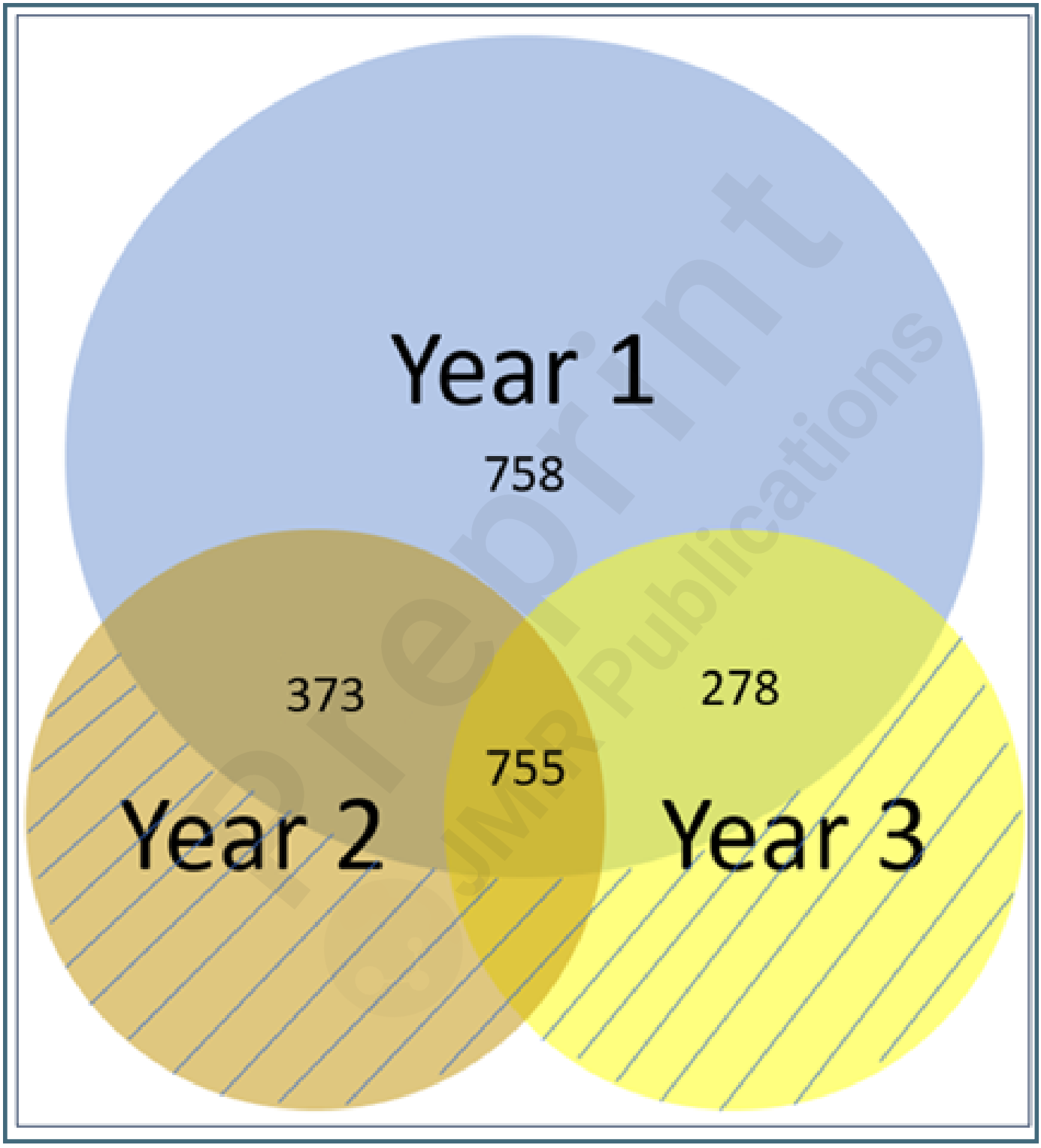
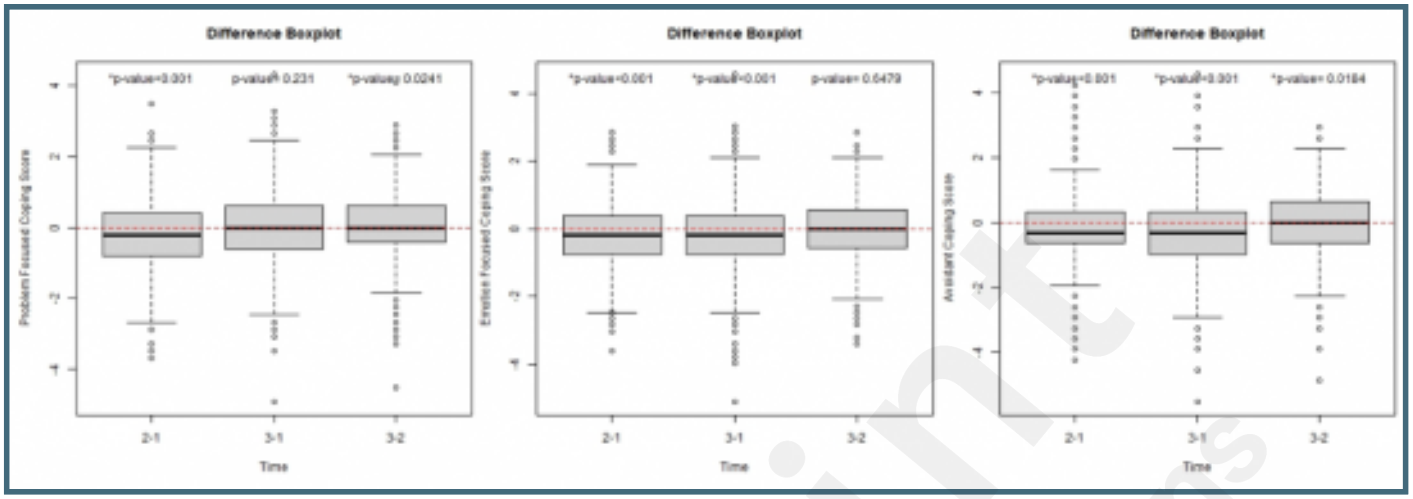
Supplementary Files

Figures

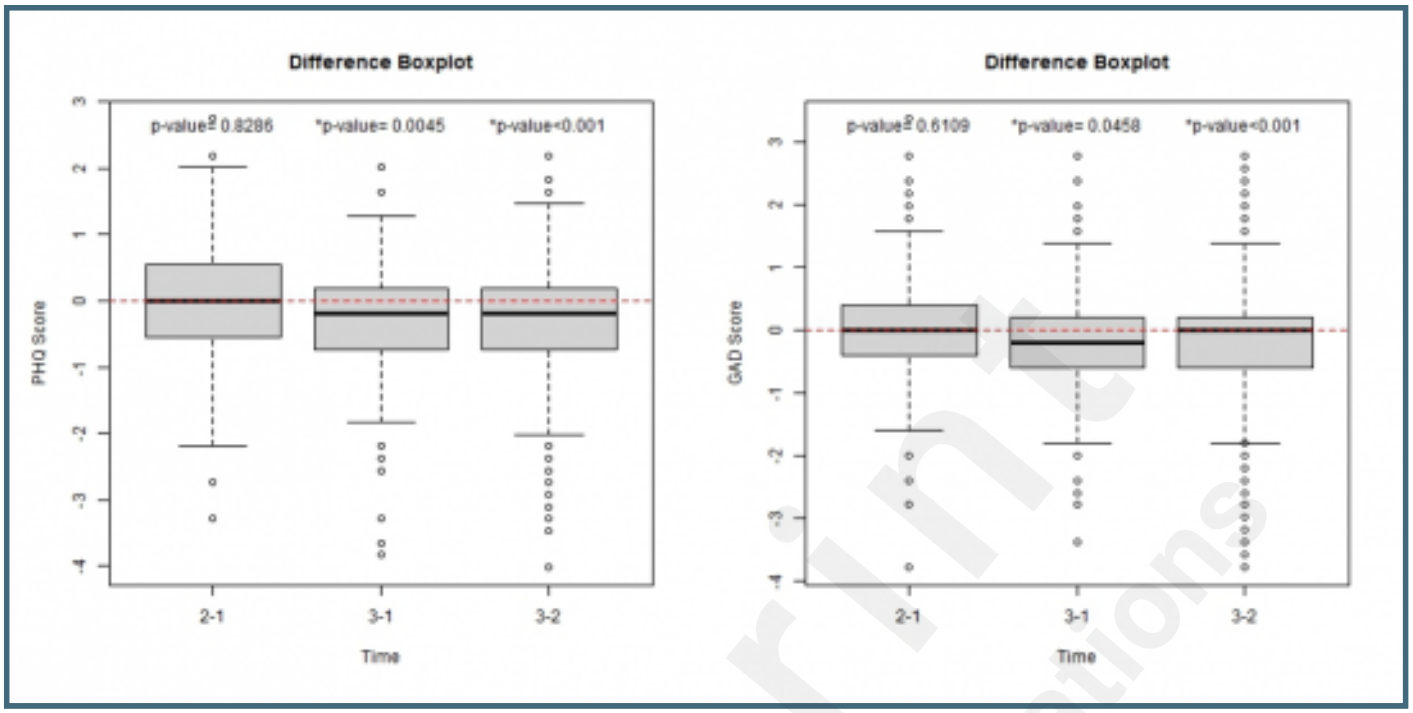
Venn Diagram of Student Participation Across the 3-Year Study Period. Year I: n=2164; Year II: n=1128; and Year III: n=1033. N=755 students participated in all 3-phases; n=373 were unique to Year I and Year II; and n=278 participants were unique to Year I and Year III.



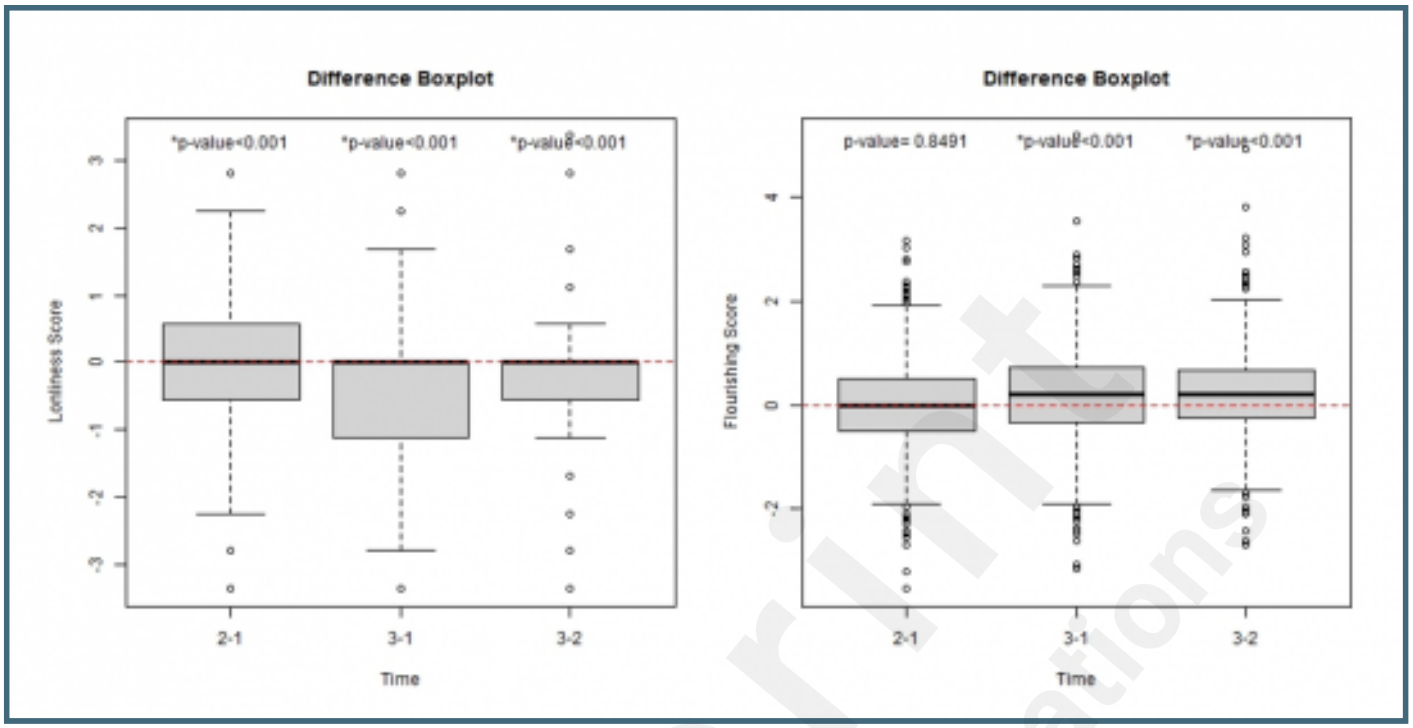
Coping Skills Across the 3-Year Study Period. The boxes in each plot depict differences between pairs of phases. Panels (a)-(c) illustrate problem-focused, emotion-focused, and avoidant coping, respectively.



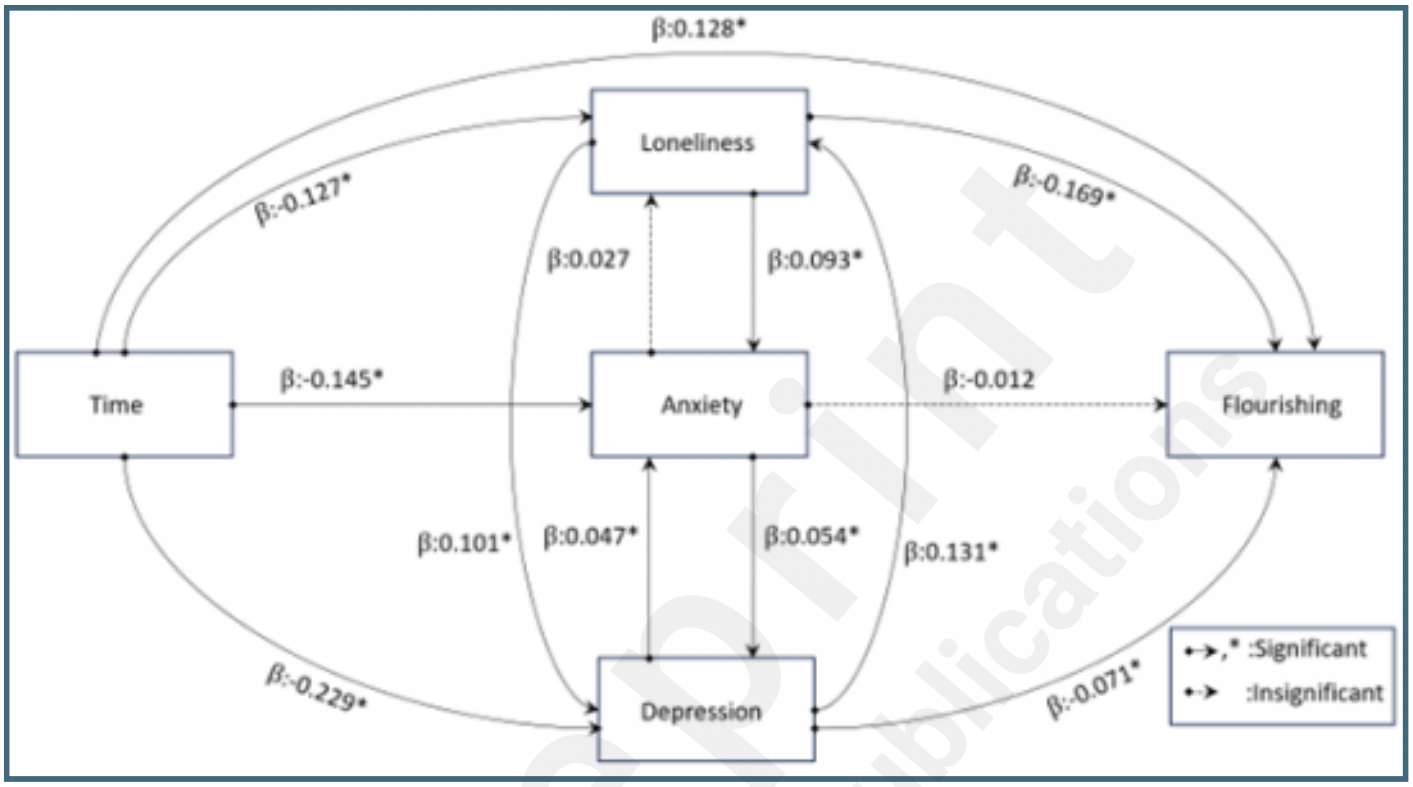
Depression (PHQ-9) and Anxiety (GAD-7) Across the 3-Year Study Period.



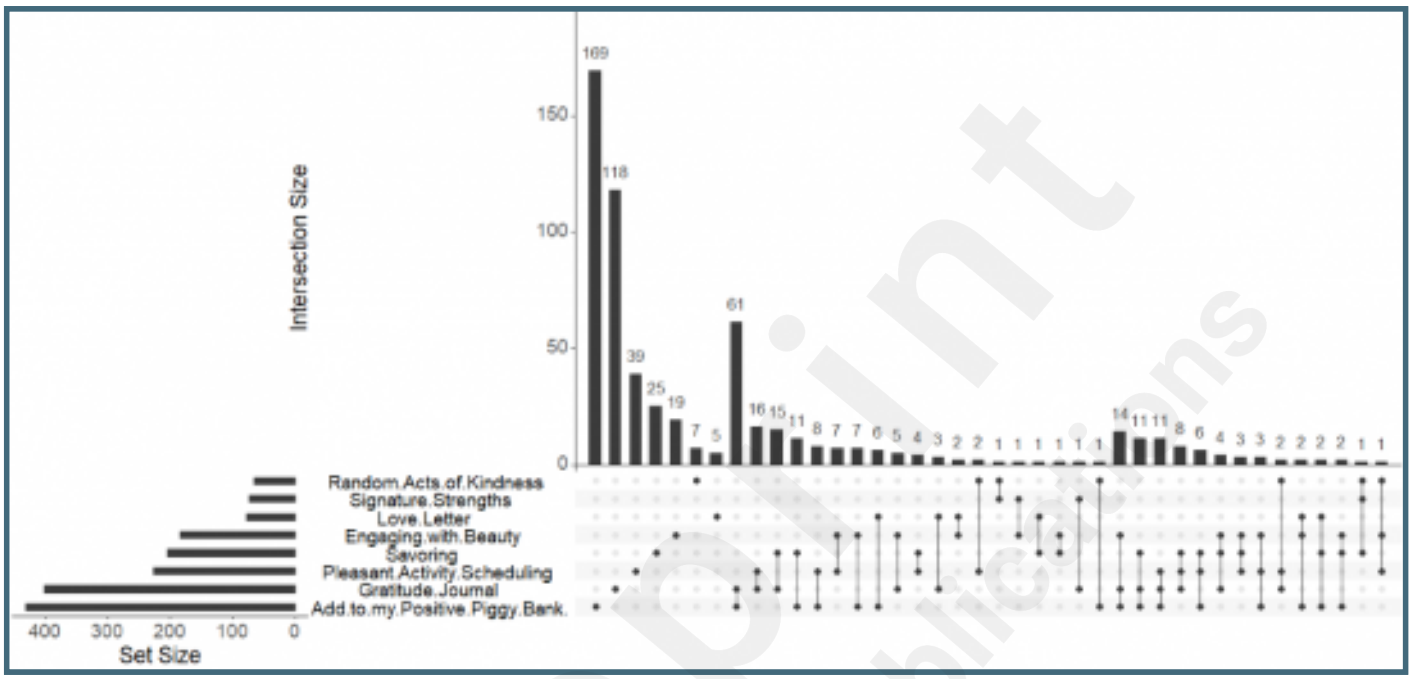
Flourishing and Loneliness Across the 3-Year Study Period.



Potential Pathways Influencing Student Flourishing. We summarize the multilevel models where the endpoints of the arrows represent the outcomes and the starting points indicate the predictors. All predictors in the models are lagged by one year, allowing them to forecast the outcomes in the subsequent year. Solid lines with star symbols denote significant p-values, while dashed lines indicate non-significant p-values. The symbol represents the estimated value in the respective model.



This UpSet plot visualizes the intersection of the positive activities engaged by students using the app in Year 1 and Year 2. The x-axis represents unique combinations of activities, while the y-axis indicates the number of users for each combination. Of note, single app usage is represented by the Set Size on the left: “Positive Piggy Bank" (431 unique users) and "Gratitude Journal" (402 unique users). Other activities included "Pleasant Activity Scheduling" (227 users), "Savoring" (205 users), and "Engaging with Beauty" (184 users). "Love Letter" (78 users) and "Signature Strengths" (74 users) had moderate engagement, while "Random Acts of Kindness" (66 users) was the least used.



Multimedia Appendixes

Roadmap 2.0 App multi-component features defined.
URL: http://asset.jmir.pub/assets/435a7fd064994ef7fab0169e0a2ffd2f.docx

Mediation analysis result between pandemic year and flourishing.
URL: http://asset.jmir.pub/assets/0e19b69c06db50a67affd0b1bcdce512.docx

TOC/Feature image for homepages

College students using cellphones. Designed by Freepik.