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Economic Evaluation of an Online Single-Session Intervention for Depression in Kenyan Adolescents

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Objective: To evaluate the costs and cost-effectiveness of *Shamiri-Digital*, an online single-session intervention (SSI) for depression among Kenyan adolescents. ***Method:*** Data were drawn from a randomized clinical trial with n = 103 Kenyan high school students (64% female, M_{age} = 15.5). All students were eligible to participate, regardless of baseline depression symptomatology. We estimated delivery costs in 2020 U.S. dollars from multiple perspectives. To account for uncertainty, we performed sensitivity analyses with different cost assumptions and definitions of effectiveness. Using number needed to treat (NNT) estimates, we also evaluated the cost required to achieve a clinically meaningful reduction in depressive symptoms. ***Results:*** In the base-case (the most realistic cost estimate), it costs U.S. $3.57 per student to deliver *Shamiri-Digital*. Depending on the definition of clinically meaningful improvement, 7.1–9.7 students needed to receive the intervention for one student to experience a clinically meaningful improvement, which translated to a cost of U.S. $25.35 to U.S. $34.62 per student. Under a worst-case scenario (i.e., assuming the highest treatment cost and the strictest effectiveness definition), the cost to achieve clinically meaningful improvement was U.S. $92.05 per student. ***Conclusions:*** *Shamiri-Digital* is a low-cost intervention for reducing depression symptomatology. The public health benefit of empirically supported SSIs is especially important in low-income countries, where funding for mental health care is most limited. Future research can compare the cost-effectiveness of online SSIs to higher-cost treatments and estimate the robustness of *Shamiri-Digital*'s effects over a longer time horizon.

What is the public health significance of this article?
Given that limited resources are available to fund mental health treatments in low-income countries, it is important to evaluate the cost-effectiveness of scalable interventions. In this study, we estimated the cost-effectiveness of *Shamiri-Digital*, an online single-session interventions for Kenyan adolescents. We found that *Shamiri-Digital* can be delivered for less than $4 per student, making it considerably less costly than traditional interventions. Estimates of *Shamiri-Digital*'s cost-effectiveness were also favorable, suggesting that it may be a useful tool for expanding access to interventions for youth depression.

Keywords: cost-effectiveness, depression, adolescents, global mental health, public health

Mental health problems are a leading cause of disability for adolescents, contributing 45% to the overall burden of disease among people aged 10–24 (Gore et al., 2011). In 2017, the World Health Organization declared depression as the leading cause of disability worldwide (Friedrich, 2017). Adolescents in low- and middle-income countries are especially vulnerable to depression, the most common mental disorder. Left untreated, depression often has serious emotional, educational, and economic consequences

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A previous manuscript (Osborn, Rodriguez, et al., 2020) has been published using the description of the results of a randomized controlled trial of *Shamiri-Digital*. The previous manuscript described the clinical trial and reported on the results from the trial. In contrast, this present submission focuses on estimating the costs and cost-effectiveness. All of the cost data, and the analyses related to cost data, are original and have not been previously published.
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(Fletcher, 2010; Lépine & Briley, 2011). Even subclinical levels of depression can be highly impairing, with subsyndromal symptoms accounting for more doctor's visits and suicide attempts than full syndromes (Ruscio, 2019). Given the prevalence of depression and its serious consequences, developing scalable treatments for depression has become a major priority in global mental health (Fairburn & Patel, 2017; Muñoz, 2010).

Traditionally, interventions to improve youth mental health have been tested and implemented in the form of manualized psychotherapies delivered by trained professionals over the course of several weeks or months (Southam-Gerow & Prinstein, 2014; Weisz et al., 2017). Although some of these interventions yield medium to large effects for youth mental health outcomes, they often require substantial time and resources to implement (Weisz et al., 2017). As a result, these interventions are insufficient to meet the population-wide needs for mental health services (Kazdin & Blase, 2011).

Additionally, the vast majority of youth in need of services do not receive any treatment. In high-income Western countries such as the United States, about 80% of youth with psychiatric disorders do not receive treatment; among those who do, 30%–60% drop out prematurely (Harpaz-Rotem et al., 2004; Merikangas et al., 2011). The situation is worse in low- and middle-income countries (LMICs), where access to treatment is especially low (Kessler & Ustun, 2008; Rathod et al., 2017). Youth face many barriers to treatment, such as high treatment costs, transportation and scheduling difficulties, and stigma associated with help-seeking (Patel et al., 2007). The cost of treatment is an especially strong barrier in LMICs, where governmental investment in mental health is particularly limited and where citizens have few resources to invest in treatment (Patel et al., 2007).

To address these challenges, there is a need for empirically supported interventions that are less costly than traditional face-to-face psychotherapy. One promising option involves interventions that do not require trained mental health professionals. A growing body of evidence suggests that digital interventions, such as those delivered through the web, reduce depression and anxiety in youth (Ebert et al., 2015). Furthermore, meta-analytic evidence suggests that online interventions for youth mental health problems can be effective in just a single session (Schleider & Weisz, 2017). However, effects of single-session interventions on depression tend to be weaker than for anxiety and conduct problems, suggesting that research on novel depression single-session interventions may be especially useful (Schleider & Weisz, 2017). As an example, some online single-session interventions centered around growth mindsets (i.e., the idea that peoples' personality traits and feelings are malleable, and people can improve through effort) have been shown to reduce depressive symptoms up to 9 months post-intervention (e.g., Schleider & Weisz, 2018).

From a cost-effectiveness standpoint, digital self-help interventions may be particularly appealing. Mental health interventions often include many resources, including provider time, client time, facilities, and transportation fees (French et al., 2018). Digital interventions can eliminate or substantially reduce costs of delivering and accessing mental health services (Warmerdam et al., 2010). Importantly, the low cost of digital interventions does not mean that they will always be *cost-effective* relative to other kinds of interventions. Sometimes, expensive interventions are more cost-effective than cheaper interventions (e.g., if intervention A is 10% more expensive but 50% more effective than intervention B, then intervention A would be considered more cost-effective even though it is more expensive). Digital interventions also have benefits beyond their low cost; as an example, they can be disseminated even in settings with a dearth of mental health professionals (Fairburn & Patel, 2017). Digital interventions also have limitations—not everyone has access to the internet, eHealth literacy is limited in some populations, and some people prefer non-digital interventions (Neter & Brainin, 2012). Nonetheless, access to digital technology has been expanding rapidly around the world, including in low- and middle-income countries (Johnson, 2021).

School-based interventions also have numerous advantages that may enhance their cost-effectiveness and scalability. First, previous meta-analytic evidence has shown that school-based prevention programs for depression tend to be effective for youth depression and anxiety (Corrieri et al., 2014). Moreover, from a dissemination and implementation standpoint, there are several factors that make school-based interventions appealing (see Chodkiewicz & Boyle, 2017). For example, because children and adolescents are mandated to attend school, school-based interventions can reach a large share of youth and expand access to care (Wasil, Park, et al., 2020; Wasil, Osborn, Venturo-Conerly, et al., 2021). Furthermore, school-based interventions can draw on existing resources (e.g., teachers, classrooms, school materials), which can reduce intervention delivery costs. Students also encounter many of their stressors and emotionally significant experiences in school, making school a natural setting in which students can learn and apply skills that promote mental health (Chodkiewicz & Boyle, 2017). Schools also serve as common settings for universal interventions (which reach all students, regardless of baseline symptom severity) and prevention programs. By reaching a large number of students, universal interventions can have population-level impacts on mental health and educational outcomes (see Greenberg & Abenavoli, 2017).

Although single-session, digital, and school-based interventions are often considered to be cost-effective, there have actually been very few economic evaluations of these interventions. In fact, there have been few economic evaluations of youth mental health interventions in general. In a recent systematic review, Sung et al. (2021) identified only nine economic evaluations of youth mental health interventions, none of which were digital interventions. Two of the studies analyzed school-based interventions for adolescents, though neither of them targeted depression. One targeted substance use (Dino et al., 2008), the other targeted obesity but had an unanticipated effect on reducing disordered weight control behaviors in adolescent girls (Wang et al., 2011), and both studies were conducted in the United States. Importantly, both interventions were found to be cost-effective (Dino et al., 2008; Wang et al., 2011). Thus, although there have been some promising data on the effectiveness and cost-effectiveness of school-based interventions for adolescents, three important gaps remain: (a) limited research has evaluated the cost-effectiveness of interventions for depression, (b) limited research has examined the cost-effectiveness of digital interventions, and (c) limited research has examined the cost-effectiveness of interventions delivered in low- and middle-income countries. Such limitations are especially important given the public health burden of depression, the growing enthusiasm toward digital interventions, and the limited mental health resources in low- and middle-income countries (Fairburn & Patel, 2017; Gore et al., 2011; Patel et al., 2007).

Encouraged by the potential advantages of online school-based interventions, and motivated to fill gaps in the existing literature, our team previously developed an online single-session intervention for mental health promotion among Kenyan adolescents (Osborn, Rodriguez, et al., 2020). Estimates suggest that 26.4%- 45.9% of school-going adolescents endorse elevated depressive symptoms (Khasakhala et al., 2012; Ndetei et al., 2008; Osborn, Venturo-Conerly, Wasil, Schleider, & Weisz, 2020; Osborn, Kleinman, et al., 2021). The elevated levels of depressive symptoms are thought to be connected to a variety of social, economic, and academic stressors faced by Kenyan adolescents (Ndetei et al., 2008; Osborn, Venturo-Conerly, Wasil, Schleider, & Weisz, 2020; Wasil, Venturo-Conerly, et al., 2021). Furthermore, access to treatment is highly limited in Kenya. With only 0.19 mental health workers per 100,000 people (World Health Organization, 2018), alternatives to provider-delivered interventions are needed. Seeking help from professionals is further limited by stigma toward mental health problems in Kenya (Ndetei et al., 2016). To circumvent this stigma, universal programs (that do not require some students to be "outed" as having mental health problems) focused on character strengths (as opposed to psychopathology) could be helpful. Additionally, to account for the low availability of providers, we reasoned that a self-guided digital intervention would be especially appropriate in Kenya.

With these contextual factors in mind, we previously evaluated *Shamiri-Digital* as a school-based mental health promotion intervention in a randomized controlled trial (Osborn, Rodriguez, et al., 2020). Adolescents randomized to the intervention experienced greater reductions in symptoms of depression than those randomized to an online study skills control condition (Osborn, Rodriguez, et al., 2020). Given that one of the potential benefits of online school-based interventions is their low cost, we sought to formally evaluate the cost-effectiveness of *Shamiri-Digital*. In doing so, we aimed to fill important gaps in the digital mental health literature, illustrate a set of methods that could be used in future evaluations of youth mental health interventions, and provide the first estimates of the cost-effectiveness of an online single-session intervention.

Thus, in this secondary analysis, we conducted an economic evaluation of *Shamiri-Digital*, a universal school-based online single-session self-help intervention for adolescents in Kenya. To estimate the cost-effectiveness of *Shamiri-Digital*, we first calculated the cost of *Shamiri-Digital* and the control condition for the base case, low-cost scenario, and high-cost scenario. Then, using number needed to treat values, we calculated the cost required to yield a clinically meaningful improvement. Finally, we calculated effectiveness-cost ratios by dividing each student's symptom change score by the cost of delivering the intervention to one student. Through this process, we aimed to address three research questions:

1. What resources are required to deliver the digital, single-session, school-based intervention to Kenyan adolescents?
2. How much does the intervention cost per student who receives it?
3. How much does it cost to produce a "clinically meaningful improvement" in depressive symptoms?

Method

Trial Design and Registration

Details about the *Shamiri-Digital* trial have been published elsewhere (Osborn, Rodriguez, et al., 2020). The randomized controlled trial tested the effects of *Shamiri-Digital* against an online study skills control condition; each condition took approximately 1 hr to complete. The intervention was delivered in school classrooms, and students were randomized 1:1 via an online random number generator. Students completed measures at baseline and 2 week follow-up. We did not assess suicidal ideation, but students were free to report concerns or adverse events to study staff, and none reported any during the trial. The trial was pre-registered at the Pan African Clinical Trials Registry (PACTR201906810558181) in accordance with WHO and ICMJE standards. All procedures were approved by the Maseno University Ethics Review Committee (MUERC) in Kenya.

Shamiri-Digital was developed and studied as a universal mental health promotion intervention; it was designed to be disseminated to a population of students regardless of their current levels of symptoms or distress. Thus, *Shamiri-Digital*, like other universal interventions, can simultaneously serve the function of prevention programs (for those who currently do not experience elevated levels of psychopathology) and interventions (for those who do). Universal mental health promotion interventions in schools have been shown to be effective across a broad array of mental health and wellness outcomes (see Wells et al., 2003 for a review).

Participants and Setting

The study took place in a private mixed-gender school in Kiambu County on the outskirts of Nairobi. Study recruitment occurred in June 2019. The school was a private school run by a community-based non-profit organization to serve primarily low-income students from across the country. The school offered full financial aid or subsidized fees (~$300) for all students. Data provided by the school indicated that approximately 82% of students received full bursary/financial aid (i.e., did not pay any tuition). In Kenya, schools with these characteristics are a feasible context for delivering online interventions, as these schools generally have computers with access to the internet (see Osborn, Rodriguez, et al., 2020). Students aged 13–18 were invited to participate, and no exclusion criteria were applied. Interested students provided informed consent or assent prior to enrollment; parental consent was obtained for minors through school administrators per MUERC guidelines. Of the 120 students invited, 103 agreed to participate.

Treatment Conditions

Students participating in the study were randomized to receive either the *Shamiri-Digital* intervention or an active control intervention focused on study skills. Students assigned to the *Shamiri-Digital* intervention received three modules: growth-mindset, gratitude, and value affirmation. The development of the original *Shamiri* intervention and its adaptation as a digital intervention have been described elsewhere (Osborn, Rodriguez, et al., 2020). In brief, the intervention was developed specifically for Kenyan adolescents. In order to circumvent stigma in Kenya, our team decided to focus *Shamiri* on character strengths as opposed to deficits or psychopathology (see Osborn, Venturo-Conerly, Wasil, Rodriguez, et al., 2020; Osborn, Wasil, et al., 2020). After reviewing literature on character strength interventions, we selected modules based on three concepts: growth mindset, gratitude, and value affirmation (see Osborn, Wasil, et al., 2020 for additional details). Growth mindset interventions have been shown to reduce depressive symptoms (e.g., Schleider & Weisz, 2018) gratitude interventions have been shown to reduce depressive symptoms and improve subjective well-being (Cregg & Cheavens, 2021), and value affirmation interventions have been shown to enhance a variety of educational and health outcomes (Cohen & Sherman, 2014). Although its mechanisms of change are not fully known, *Shamiri* is hypothesized to improve depressive symptoms through cognitive changes (e.g., believing that one can improve through effort, shifting one's attention toward positive things, reflecting on one's personal values) and behavioral changes (e.g., spending more time on activities that may lead to personal growth, expressing gratitude, and acting in accordance with one's personal values).

In *Shamiri-Digital*, the three modules of *Shamiri* were adapted for an online self-help format. In the growth mindset module, students learned about how the brain changes in response to challenges, read a growth testimonial written by a Kenyan peer, and wrote a story about a time they grew as a result of a challenge. In the gratitude module, students completed the "three good things" exercise, in which they reflected on three things in their lives for which they were grateful. In the value affirmation module, students completed reflected on a personal value and wrote about a time in which they used their values to guide their life decisions. All three modules were completed in one sitting.

The study-skills control condition included two modules: note-taking skills and effective study habits. It was designed to have a similar structure to the *Shamiri-Digital* intervention and to require a similar amount of effort and time. Both *Shamiri-Digital* and the study skills control condition were both developed specifically for Kenyan adolescents (see Osborn, Rodriguez, et al., 2020 for details).

Measures

Students were assessed at baseline and a 2-week follow-up. Outcome measures assessed depressive symptoms, anxiety symptoms, and subjective well-being. The program produced statistically significant reductions in depressive symptoms for the full sample, $d = 0.50$, 95% CI [.00, 1.06] as well as the clinically elevated subsample, defined as the group of individuals who reported a PHQ-8 score >=10 at baseline, $d = 0.83$, 95% CI [.31, 1.35]. The intervention did not have statistically significant effects on anxiety or subjective well-being (readers interested in these analyses should see Osborn, Rodriguez, et al., 2020). For the present cost-effectiveness analyses, we focus on the intervention's effects on depressive symptoms.

Depressive symptoms were measured using the Patient Health Questionnaire-8 (PHQ-8; Kroenke & Spitzer, 2002). Each item is scored from 0 (*not at all*) to 3 (*nearly every day*) with higher scores indicating greater levels of depressive symptoms. The PHQ-8 is identical to the PHQ-9 but lacks the suicide item (Kroenke & Spitzer, 2002); we removed the suicide item because previous research in Kenya has suggested that school administrators consider the suicide item stigmatizing and alienating for students (Osborn et al., 2020). The PHQ-8 has demonstrated adequate internal consistency and discriminant validity with Kenyan adolescents (Osborn et al., 2020). In one study, 46% of Kenyan adolescents reported scores at or above the cutoff for "moderate depression," leading the authors to speculate that the PHQ-8 may have high sensitivity but potentially low specificity (Osborn et al., 2020). However, to our knowledge, no previous study has examined the sensitivity and specificity of the PHQ-8 relative to structured diagnostic interviews derived from western conceptualizations of depression or locally-derived assessments. Nonetheless, in one study, the PHQ-8 evidenced considerable content overlap with a locally-developed measure of depressive symptoms, and the correlation of the PHQ-8 with the locally-developed measure was $r = 0.76$ (Osborn, Kleinman, et al., 2021). Cronbach's α for the PHQ-8 in the present study was 0.73.

Cost Assessment

To evaluate the relationship between intervention costs and outcomes, we were informed by literature on cost-effectiveness analyses of mental health interventions (Yates, 2009). Under this approach, *costs* represent the value of resources used to provide an intervention, *effectiveness* represents the non-monetary outcome of the intervention, and cost-effectiveness ratios illustrate the relationship between costs and effectiveness.

We used a microcosting approach to estimate the costs of resources required to deliver the interventions (Neumann & Sanders, 2017). We consider costs from three perspectives: *school perspective*, *researcher perspective*, and *societal perspective*. The school perspective included an estimation of the cost of teachers' time (i.e., time required to oversee the administration of the intervention) and the cost of providing internet. The researcher perspective included costs that our research team incurred to deliver the intervention (e.g., the cost of hosting the intervention on a website, the cost of backup internet data). Finally, the *societal perspective* represents the total cost (the sum of the costs from the school perspective and researcher perspective). Economists recommend adopting the societal perspective when estimating intervention costs because it provides the most comprehensive estimate of the resources required to deliver an intervention, which is especially relevant to policy makers (Neumann & Sanders, 2017).

We also conducted a sensitivity analysis to address uncertainty associated with our cost assumptions, which can impact the reliability of our cost-effectiveness findings (Jain et al., 2011). We estimated costs under three scenarios, each with a different set of assumptions: the *base case*, the *low-cost scenario*, and the *high-cost scenario*. The base case is intended to reflect the most realistic estimation of costs. The low-cost scenario assumes a more favorable (i.e., less costly for stakeholders) set of circumstances for implementation, and the high-cost scenario assumes a less favorable (i.e., more costly for stakeholders) set of circumstances (see Table 1).

Base Case

We first estimated all costs in Kenyan shillings. We then converted Kenyan shillings to U.S. dollars using a live mid-market rate accessed on June 14, 2020. Details about cost calculations in the base case, low-cost, and high-cost scenarios are presented in Tables 1 and 2. Under the base case, the cost per student totaled \$3.57 from the societal perspective (\$1.43 from the school perspective and \$2.14 from the researcher perspective).

Table 1
Description of Cost Estimations Per Student Under Different Scenarios

Base case scenario	Description of cost per student calculation
School: Teacher	Including fringe benefits, the median monthly salary for a Kenyan teacher in 2020 was 66,895 shillings (https://majira.co.ke/2020-new-salary-scale-for-teachers-after-tsc-promotion/) or $628.03 per month. Assuming a 40-hr work week and 4 weeks in a month, this is equivalent to $3.93/hr. We needed 6 hr of teacher time to deliver the intervention to 103 students. $3.93/hr × 6 hr/103 students = $0.23/student
School: Internet	The cost for 1 min of internet is $0.02 (Vivi, 2018) and the intervention lasted 60 min. $.02 × 60 = $1.20/student
Research: Web hosting	$100/103 students = $0.97/student.
Research: Back-up internet	$120/103 students = $1.17/student
Total societal cost/student	$3.57
Low-cost scenario	
Research: Web hosting	Description above. $0.97/student
Total societal cost/student	$0.97
High-cost scenario	
Base case	Description above. $3.57/student
Research: Research assistants	Two research assistants each received a $150 stipend for the duration of the study. $300/103 students = $2.91 student
Research: Materials and printing	$100/103 students = $0.97/student
Research: Maseno University ethics review committee permit	$110/103 students = $1.07/student
School: Facilities (annual cost)	$0.42[a] × 56 m^2,[b] = $787.27/m^2; $787.27/m^2/1565.25 hr (40 hr/week for 9 month school year) × 6 teachers/103 students = $0.001 student
School: Computers, monitors, keyboards, mouses, chairs, and desks	Value from Table 2: $0.97/hr
Total societal cost/student	$9.49/student

[a] Cost per m^2 for Kenyan commercial property (https://www.property24.co.ke/commercial-property-to-rent-in-mombasa-rd-107863085). [b] Typical size of a secondary school classroom (Kenyan Ministry of Education, 2015).

Low-Cost Scenario

Under the low-cost scenario, we altered the base case in three ways. First, we assumed that teachers who oversee the administration of the intervention could perform work (e.g., grading, preparing class materials) while overseeing the administration of the intervention, thus eliminating the opportunity cost of their time. Second, we assumed that schools implementing the intervention would not incur costs for internet or backup internet data because many schools already invest in stable internet. Of note, we also did not need to use any of the backup internet data we purchased in the present trial. As a result, we eliminated the cost of the internet and backup internet data for the low-cost scenario. Third, we assumed that a school implementing the intervention would not incur new facility and hardware costs because the school would have already invested in those resources. The total cost per student from the low-cost perspective was $0.97 (all costs were incurred from the researcher perspective).

High-Cost Scenario

Under the high-cost scenario, we altered the base case in five ways; three of these changes related to the researcher perspective. These resources and costs were added to the high-cost scenario because they were necessary to evaluate the effectiveness of the intervention, which may be relevant to researchers but less relevant for efforts to disseminate the intervention outside of clinical trials. We included the stipends of two research assistants who supported the data collection and data entry for the study, the costs of printing recruitment materials, and cost of receiving an Institutional Review Board (IRB) permit from the Maseno University Ethics Review Committee (see Table 1). The final two changes related to the school perspective. In addition to the cost of teachers and internet, we included the cost of facilities and materials (computer equipment, desks, and chairs). We did not include these costs in the base case because many schools already invest in these resources, and therefore would not incur additional facility or material costs if they

Table 2
Total Cost Estimations of Computer and Office Equipment

Equipment	2020 KSH	2020 USD	Quantity	Work hours in 9 months in 7 years[a]	KSH/hr	USD/hr
Computer + monitor + keyboard + desktop	38000.00	$352.23	18[b]	7826.25[c]	87.40	$0.81
Computer lab desks	6000.00	$55.62	18	10956.75	9.86	$0.09
Desk chairs	4500.00	$41.72	18	10956.75	7.39	$0.07
				Total USD/hr	104.65	$0.97

Note. KSH = Kenyan Shillings; USD = U.S. Dollars.
[a] 7 years is the determinable useful life of office furniture (U.S. Department of the Treasury, 2017). [b] Number of computers per classroom. [c] Number of working hours (40 hr/week) in 9 months in 5 years, the determinable useful life of computer hardware (U.S. Department of the Treasury, 2017).

implemented the intervention. Total costs in the high-cost scenario were $9.49 per student ($2.40 from the school perspective and $7.09 from the researcher perspective).

Effectiveness Analysis

Just as there are multiple ways to estimate costs, there are multiple ways to estimate effectiveness. In our trial of *Shamiri-Digital*, we analyzed the impact of the intervention relative to the control group by applying mixed-effects linear models in which depressive symptoms were a continuous variable (Osborn, Rodriguez, et al., 2020). Here, we present one set of cost-effectiveness analyses that treat symptoms as categorial (cost per clinically meaningful improvement) and one set that treat symptoms as continuous (effectiveness-cost ratios).

Operationalizing outcomes categorically is consistent with previous work on cost-effectiveness analyses (French et al., 2018). Although continuous approaches to the analysis of depression have advantages (Ruscio, 2019) particularly for clinicians, a cost per one-point reduction on a symptom inventory is more challenging for policy makers to interpret than a cost per "cured person." Because "cure" implies the absence of relapse, the term "cure" may be too strong to apply in many mental health studies—especially ones like ours with a limited follow-up duration. Furthermore, many students in our sample reported subclinical levels of depressive symptoms at baseline. Therefore, we prefer to think about the cost per "clinically meaningful improvement." While analyses that view symptom improvement as categorical are useful for policymakers and health economists, there are also several limitations of conceptualizing mental health outcomes dichotomously (Ruscio, 2019). As a result, we also present effectiveness-cost ratios in which symptoms are treated continuously.

We applied three different definitions of clinically meaningful improvement. First, we applied the "standard definition" that has been applied to studies using the PHQ-9. Under this definition, clinically meaningful improvement occurs if an individual (a) starts with a score $\geq$10 and ends with a score $\leq$9, and (b) experiences a reduction of at least 50% of their pre-treatment score (McMillan et al., 2010). As an example, in order to qualify as a case of clinically meaningful improvement under this definition, an individual who starts with a PHQ-9 score of 12 would need to drop to a score of six or lower. Second, we applied the reliable and clinically significant change (RCSC) criterion C which has also been applied to studies using the PHQ-9. Under this definition, clinically meaningful improvement occurs if an individual (a) starts with a score $\geq$10 and ends with a score $\leq$9, and (b) experiences a reduction of at least five points (McMillan et al., 2010). As an example, in order to qualify as a case of clinically meaningful improvement under this definition, an individual who starts with a PHQ-9 score of 12 would need to drop to a score of seven or lower. By definition, all individuals who meet the standard definition must also meet the RCSC Criterion C definition. That is, if an individual experienced a reduction of symptoms of 50% or more, and their score was 10 or greater at baseline, then their score must have improved by five points or more. A limitation of these approaches is that they require individuals to start with elevated scores for depressive symptoms. In universal interventions like *Shamiri-Digital*, in which some participants do not begin with elevated symptoms, alternative approaches may be useful.

Because subsyndromal levels of depressive symptoms are still associated with substantial amounts of distress and impairment (Ruscio, 2019), it is important to identify clinically meaningful changes that occur in individuals who did not begin a study with elevated depressive symptoms. As a result, we applied a third definition that allows us to detect change in our full sample. Under this definition, clinically meaningful improvement occurs for any individual who experiences a reduction of at least three points, as well as a 50% reduction in symptoms. All individuals who meet the standard definition must also meet this definition (as explained above).

For each definition of clinically meaningful improvement, we calculated the *number needed to treat* (NNT) required to result in a clinically meaningful improvement. The NNT compares the proportion of improvements in the intervention group to the proportion of improvements in the control group. As such, the NNT provides an estimate of the number of people that need to receive the intervention in order to result in one additional improvement (i.e., one improvement above what would be expected if everyone received the control condition).

One consideration is that each definition of clinically meaningful improvement requires students to have a minimum score at baseline (a score of 10 for the standard definition and RCSC Criterion C; a score of six for the third definition). We focus our cost-effectiveness analyses on the NNT estimates that include *all* students instead of those who started with elevated symptom scores. This approach provides a more conservative estimate of NNT. Nonetheless, for each definition of clinically meaningful change, we report the NNT estimate that uses all students and the NNT estimate that only includes students with minimum starting scores (i.e., a starting score of 10 under the standard definition and the RCSC Criterion C; a stating score of six under the definition of 3-point change and 50% improvement).

Our definitions of clinically meaningful improvement should be interpreted in light of the fact that our study had a 2-week follow-up. As a result, our data only support inferences about short-term responses to the intervention rather than sustained responses (see Frank et al., 1991).

Cost-Effectiveness Analysis

We calculated the relationship between effectiveness and societal perspective costs by calculating effectiveness-cost ratios for each student, which divides a student's PHQ-8 change score by the total cost per student. Multiplying the cost per student by the NNT, we calculated the cost required to produce a clinically meaningful improvement; we completed this procedure for each of our three definitions of clinically meaningful improvement.

In many cost-effectiveness analyses, the two or more comparator treatments require different types and amounts of resources in order to be delivered. In addition, there are usually variations in treatment retention for treatments with more than one session. Differences in treatment delivery resources and patient retention can lead total costs to differ between treatments. In our study, however, *Shamiri-Digital* and the active study skills control condition required the same amount of resources to deliver, and each was delivered in a single session. Thus, treatment costs per student did not differ between conditions. As a result, some standard cost-effectiveness approaches (e.g., incremental cost-effectiveness ratios, two-part models) were not appropriate for our study. Instead, we focus on estimating costs, NNTs, and the cost per clinically meaningful improvement.

Data Analysis Plan

Analyses were performed in R (R Core Team, 2017). Three students had missing item-level data (i.e., they filled out seven of the eight PHQ-8 items). Responses for these students were imputed via mean-level imputation. We preferred mean-level imputation over multiple imputation because multiple imputation techniques lack a theoretical basis and are more difficult to interpret (see White et al., 2011). Two students (both of whom were in the control group) did not complete any measures at follow-up and were excluded from the present analyses.

Results

Demographics

Our sample consisted of 101 students (see Table 3 for demographic characteristics). Students reported elevated depressive symptoms, with a mean PHQ-8 score of 10.13 ($SD = 5.0$). These rates are consistent with previous studies of Kenyan adolescents (Osborn et al., 2020; Osborn, Venturo-Conerly, et al., 2021). Using scoring guidelines from western samples (see Kroenke & Spitzer, 2002), 55% of our sample endorsed elevated symptoms at baseline (meeting the cutoff for "moderately depressed"). In our analyses, we refer to these individuals—those who reported a baseline PHQ-8 score >=10—as the clinically elevated subsample.

Effectiveness

Relative to students in the control condition, students in the *Shamiri-Digital* condition reported significantly greater reductions in depressive symptoms (see Table 4; see also Osborn, Rodriguez, et al., 2020 for additional details).

The NNT metrics for each definition of clinically meaningful change are presented in Table 5. Furthermore, the median duration (including baseline questions and post-intervention questions) of the two conditions did not differ (median $\text{duration}_{\text{Shamiri-Digital}} =$ 74.13 min, median $\text{duration}_{\text{Study Skills}} = 72.16$ min, $U(50, 51) =$ 1,555, $p = .67$).

Table 3
Sample Characteristics at Baseline

Variable	*Shamiri-Digital* intervention ($N = 50$)	Study-skills control ($N = 51$)
Age *M* (*SD*)	15.36 (1.21)	15.76 (1.21)
Sex *n* (%)		
Female	35 (70.00)	31 (60.78)
Male	15 (30.00)	20 (39.22)
PHQ-8 *M* (*SD*)	10.60 (5.37)	9.94 (4.63)
Form		
1	22 (44.00)	20 (39.22)
2	13 (26.00)	13 (25.49)
3	15 (30.00)	18 (35.29)

Note. PHQ-8 = patient health questionnaire-8.

Standard Definition (≥10 to ≤9 and ≥50% Reduction)

Among the 101 students, 56 reported baseline PHQ-8 scores of 10 or greater ($n = 28$ per condition). In the intervention group, 11 of the 28 (39%) experienced a clinically meaningful improvement when applying the standard definition; in the control group, 4 of the 28 (14%) experienced a clinically meaningful improvement (see Table 5 for NNTs using the full sample and the clinically elevated subsample).

Reliable and Clinically Significant Change (RCSC) Criterion C (≥10 to ≤9 and ≥5 Point Reduction)

In the intervention group, 12 of the 28 (43%) students experienced a clinically meaningful improvement when applying RCSC Criterion C; in the control group, 6 of the 28 (21%) experienced a clinically meaningful improvement (see Table 5 for NNTs). All 15 students who met the standard definition also met the RCSC Criterion C definition of clinically meaningful improvement.

Reduction of Three or More Points and 50% Reduction

Among the 101 students, 92 reported baseline PHQ-8 scores of three or greater ($n = 45$ in the intervention group and $n = 47$ in the control group). In the intervention group, 12 of the 45 (27%) experienced a meaningful improvement; in the control group, 7 of the 47 (15%) experienced a meaningful improvement (see Table 5 for NNTs). All 15 students who met the standard definition also met this definition of clinically meaningful improvement, and 15 of the 18 students who met the RCSC Criterion C definition also met this definition of clinically meaningful improvement.

Cost-Effectiveness

The cost required to produce one clinically meaningful improvement ranged from $25.35 to $34.62 in the base case. The costs varied depending on the definition of clinically meaningful improvement and the cost scenario (see Table 6).

Effectiveness-Cost Ratios

We calculated an effectiveness-cost ratio for each student. In the intervention group, the average effectiveness-cost ratio was 0.5 ($SD = 1.47$); this indicates that students, on average, reported a 0.5-point reduction on the PHQ-8 per dollar spent to deliver the intervention, from the societal perspective. In contrast, the average effectiveness-cost ratio in the control group was −0.06 ($SD = 1.26$); on average, control group students did not experience an improvement.

Discussion

We estimated the cost-effectiveness of *Shamiri-Digital*, an online-single session intervention for mental health promotion among Kenyan adolescents. We estimated that the intervention cost only $3.57 to disseminate per student. We also estimated that for every 7–10 students who received *Shamiri-Digital,* one student experienced a clinically meaningful improvement. Thus, it cost about $25 to $35 to produce one clinically meaningful improvement.

Table 4
Depressive Symptoms at Baseline and 2-Week Follow-Up

Sample	*Shamiri-Digital* intervention group ($N = 50$) Baseline M (SD)	2-week follow-up M (SD)	Study-skills control group ($N = 51$) Baseline M (SD)	2-week follow-up M (SD)	Cohen's d, based on mean gain score [95% CI]
Full sample	10.60 (5.37)	8.35 (4.64)	9.94 (4.63)	10.20 (4.73)	0.52 [0.02, 1.01]
Elevated subsample	13.48 (3.01)	8.61 (4.84)	13.29 (3.01)	11.3 (5.04)	0.94 [0.23, 1.65]

Note. See Osborn, Rodriguez, et al. (2020) for a complete description of treatment outcome analyses. The elevated subsample consists of individuals who reported scores greater than or equal to 10 on the PHQ-8 at baseline. The estimates provided in this table differ slightly from those reported in Osborn, Rodriguez, et al. (2020) due to differences in imputation approaches. Osborn, Rodriguez, et al. (2020) applied multiple imputation for all participants ($n = 103$), whereas we applied mean-level imputation for participants who filled out measures at baseline and follow-up ($n = 101$).

Single-session interventions, like *Shamiri-Digital*, have the potential to be cost-effective, even if they produce lower average effects than higher-intensity treatments. Empirically supported treatments for youths generally last more than 3 months; a recent meta-analysis showed a mean of 16.54 sessions for the 447 treatments evaluated (Weisz et al., 2017). Extensive resources are invested to train clinicians to deliver and implement these interventions (Weisz et al., 2017). Although these interventions can be highly effective, there have been major challenges in scaling up the delivery of these high-intensity interventions. These challenges are especially impactful in LMICs, where financial resources for mental health care are scarce and there is a dearth of trained mental health providers (Fairburn & Patel, 2017; World Health Organization, 2018).

With this in mind, our findings suggest that single-session digital interventions could help reduce the societal cost of delivering mental health interventions and help to expand access to care in LMICs. Digital self-help interventions can eliminate provider costs, as well as costs associated with renting, maintaining, and staffing an office or clinic. Furthermore, digital mental health interventions are flexible, as they can be disseminated in situations where in-person services are not feasible (Wasil, Taylor, et al., 2021). Importantly, the public health impact of a digital intervention will not only be determined by the number of people who receive it, but also by the effectiveness of the intervention. Although there are many publicly available digital interventions (see Wasil, Gillespie, Shingleton, et al., 2020), these interventions only include a limited range of evidence-based practices (Wasil et al., 2019; Wasil, Gillespie, Patel, et al., 2020), and very few of them have peer-reviewed data to support their efficacy (Lau et al., 2020). Nonetheless, even low-cost interventions with conventionally small or medium effect sizes can be cost-effective. This principle is illustrated by the following example: with $1,000, an intervention that costs $5 per person could be disseminated to 200 people, whereas an intervention that costs $1,000 (e.g., 10 sessions of individual therapy costing $100 per session) could be disseminated to only one person. Thus, even if the $5 intervention were 1/100th as effective as the $1,000 intervention, the former could be more cost-effective. At the same time, it is important to note that low-intensity interventions and high-intensity interventions may serve different populations, and direct comparisons between the two kinds of interventions should be interpreted cautiously.

Table 5
Number Needed to Treat to Achieve a Clinically Meaningful Improvement

Definition of Clinically Meaningful Improvement	Treatment: Intervention	Treatment: Control	Number Needed to Treat (NNT): Full sample	Number Needed to Treat (NNT): Clinically elevated subsample[a]
Standard[a]	39%	14%	7.1[c]	4.0[d]
RCSC criterion C[a]	43%	21%	8.2[e]	4.7[f]
3-point reduction and 50% improvement[b]	27%	15%	9.7[g]	8.5[h]

[a] For the standard definition and the RCSC Criterion C definition of clinically meaningful change, "clinically elevated subsample" refers to participants reporting baseline PHQ-8 scores of 10 or greater. For the 3-point reduction and 50% improvement definition of clinically meaningful change, "clinically elevated subset" refers to participants reporting baseline PHQ-8 scores of six or greater. [b] "Subset of sample" refers to participants reporting baseline PHQ-8 scores of three or greater. [c] 95% CI [3.6–177.6]. [d] 95% CI [2.1–36.4]. [e] 95% CI: Number needed to harm 40 to number needed to treat 3.7. [f] 95% CI: Number needed to harm 14.2 to number needed to treat 3.1. [g] 95% CI: Number needed to harm 3.9 to number needed to treat 20.7. [h] 95% CI: Number needed to harm 3.6 to number needed to treat 21.7.

We conducted sensitivity analyses for our estimates of costs and our estimates of effectiveness. These analyses illustrated how uncertainty in cost input parameters and operationalizations of "effectiveness" can affect an intervention's estimated cost, effectiveness, and cost-effectiveness. For example, the societal cost to deliver *Shamiri-Digital* ranged from $0.97 per student in the low-cost scenario to $9.49 per student in the high-cost scenario. Either estimate is a small fraction of the typical amount of money that clients would pay for just 1 hr of psychotherapy with a licensed private-pay provider. Recent estimates from the United States suggest that private-pay clients can expect to pay $60–$120 for a 45–60 min session, or up to $250 per session in major cities (Thervo, 2020).

Although it is ideal to compare cost-effectiveness estimates across studies, it is difficult to make direct comparisons when there are differences in outcomes, study methodologies, and settings. With this in mind, a recent systematic review identified two economic evaluations of school-based mental health interventions; neither targeted depression, and both were conducted in the United States. One intervention was "Not on Tobacco," a teacher-led, smoking cessation intervention which involved 10 weekly 50-min sessions with groups of American adolescents. The

Table 6
Cost Required to Result in a Clinically Meaningful Improvement

Definition of Clinically Meaningful Improvement	Base case	Low-cost scenario	High-cost scenario
Standard	$25.35	$6.89	$67.38
RCSC criterion C	$29.27	$7.95	$77.82
3-point and 50% reduction	$34.62	$9.41	$92.05

investigators estimated that the intervention would cost $3,362.61 to deliver to 100 students (corresponding to a cost of $33.63 per student in 2000 USD, or $51.42 in 2020 USD after adjusting for inflation), and the intervention would cause 10 adolescents to quit smoking for every 100 adolescents who receive the intervention (Dino et al., 2008). The other intervention was "Planet Health," a teacher-led obesity intervention which involved 32 sessions which were incorporated into math, science, language arts, social studies, and physical education classes (Wang et al., 2011). The investigators estimated that the intervention would cost $46,803 in 2010 USD (or $55,751 in 2020 USD) to prevent one case of bulimia nervosa (Wang et al., 2011). Readers may note that the cost of disseminating *Shamiri-Digital* ($3.57 per student) was considerably lower than that of these two aforementioned interventions. This may reflect, in part, the fact that *Shamiri-Digital* is an online single-session intervention (with minimal burden on teacher or school staff time). However, comparisons between our study and these two previous studies should be interpreted cautiously for at least three reasons: (a) target problems differed across studies (i.e., our study focused on depression, as opposed to smoking or bulimia), (b) methodologies used to estimate the intervention costs and effectiveness varied considerably, and (c) our study was conducted in Kenya, where costs are lower than in the United States.

Our findings raise the possibility that low-intensity treatments implemented in LMICs may be cost-effective alternatives or supplements to existing interventions. Furthermore, by transparently describing which costs were included and excluded in each scenario, and by operationalizing effectiveness in different ways, our sensitivity analyses provide a richer set of cost-effectiveness analyses. In future economic evaluations, we encourage investigators to apply similar methods to acknowledge the uncertainty around cost, effectiveness, and cost-effectiveness estimates. A detailed description of the methods we used in our study (as well as other economic evaluation methods) can be found in Yates (1996) manual. We also direct readers to Sung et al. (2021) for additional resources and recommendations for conducting economic evaluations for mental health interventions.

Our findings offer several directions for future research. First, there is a great need for additional economic evaluations of interventions for youth. A recent systematic review found that there were only nine economic evaluations of youth mental health interventions, none of which were evaluations of digital interventions (Sung et al., 2021). Second, future research is needed to better understand *for whom* low-cost interventions are effective. This body of work could inform stepped care systems, in which data-driven methods are used to assign some youths to low-intensity services and others to high-intensity services. Third, additional research is needed to directly compare the cost-effectiveness of different mental health treatment delivery formats. Fourth, future work could directly compare the cost-effectiveness of universal interventions and targeted interventions. Relative to universal interventions, targeted interventions may require additional time and resources (e.g., administering assessments in order to identify individuals with elevated concerns), which would in turn increase their costs. Finally, future work is needed to develop additional low-intensity digital mental health interventions for youths. Such interventions may be especially impactful if they incorporate evidence-based practices that are rarely included in existing interventions and are deployed in settings where they can sustainably attract users (Wasil, Weisz, & DeRubeis, 2020).

Our study should be interpreted in light of its strengths and limitations. One strength is that we used data from a randomized controlled trial, allowing us to estimate the effectiveness of *Shamiri-Digital* relative to an active control group. Additionally, because the control group matched *Shamiri-Digital's* duration and structure, the costs did not differ between two conditions. Another strength is that we conducted sensitivity analyses to address uncertainty in our cost and effectiveness estimates. One limitation of our study is that cost data were estimated retroactively; prospectively tracking and monitoring costs could yield more precise estimates. Another limitation is that we only collected follow-up data at the 2-week timepoint. This limitation is common among youth mental health trials; meta-analytic data suggest that trials generally only measure post-intervention effects (Weisz et al., 2017). Nonetheless, studies with longer follow-up periods are needed to understand how long the effects persist, which would have major implications for cost-effectiveness evaluations. Relatedly, our definitions of clinically meaningful change are only meant to describe short-term response to the intervention; future research will be needed to understand if any students experience long-term recovery from online single-session interventions (see Wasil, Osborn, Weisz, et al., 2021). Finally, results from the trial come from students from one Kenyan high school. Additional research will be necessary to assess the degree to which these findings generalize to other populations.

Overall, our findings highlight the low cost and potential cost-effectiveness of a digital single-session intervention in a LMIC. For many decades, clinical scientists have focused on estimating the effectiveness of interventions, with little empirical consideration of their costs. To address the treatment gap, we believe it will be essential for intervention scientists to apply methods to quantify the costs and cost-effectiveness of their intervention. By doing so, the field can better understand how to allocate limited resources to best serve those in need. Such work is especially important in LMICs, where resources for mental health care are most limited.

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