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A review of antimicrobial stewardship training in medical education

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Abstract

Objectives: We reviewed the published literature on antimicrobial stewardship training in undergraduate and postgraduate medical education to determine which interventions have been implemented, the extent to which they have been evaluated, and to understand which are most effective.

Methods: We searched Ovid MEDLINE and EMBASE from inception to December 2016. Four thousand three hundred eighty-five (4385) articles were identified and underwent title and abstract review. Only those articles that addressed antimicrobial stewardship interventions for medical trainees were included in the final review. We employed Kirkpatrick's four levels of evaluation (reaction, learning, behaviour, results) to categorize intervention evaluations.

Results: Our review included 48 articles. The types of intervention varied widely amongst studies worldwide. Didactic teaching was used heavily in all settings, while student-specific feedback was used primarily in the postgraduate setting. The high-level evaluation was sparse, with 22.9% reporting a Kirkpatrick Level 3 evaluation; seventeen reported no evaluation. All but one article reported positive results from the intervention. No articles evaluated the impact of an intervention on undergraduate trainees' prescribing behaviour after graduation.

Conclusions: This study enhances our understanding of the extent of antimicrobial stewardship in the context of medical education. While our study demonstrates that medical schools are implementing antimicrobial stewardship interventions, rigorous evaluation of programs to determine whether such efforts are effective is lacking. We encourage more robust evaluation to establish effective, evidence-based approaches to training prescribers in light of the global challenge of antimicrobial resistance.

Keywords: Antimicrobial stewardship, antimicrobial resistance, antibiotic prescribing, undergraduate medical education, postgraduate medical education

Introduction

Antimicrobial resistance results from a host of factors, including improper antimicrobial prescription, and is an emergent problem. The next generation of physicians must be prepared to face this dilemma as antimicrobial stewardship becomes increasingly vital in the treatment of patients in all fields.

Traditionally, antimicrobial stewardship programs (ASP) have been initiated to address the issue of antimicrobial resistance. Education, as a mainstay feature of these programs, is considered essential to teaching the knowledge necessary for effective stewardship, and can influence physicians' prescribing behaviour.[1-3] Several educational interventions have been shown to improve antimicrobial prescribing practices and infection control.[4-7] The majority of antimicrobial stewardship education has involved practicing physicians, specifically targeting prescribing habits with the goal of modifying their approach to antimicrobial prescription.[1,8] Yet changing the behaviour of practicing physicians has proven difficult.[6]

Few studies have sought to understand the type or efficacy of teaching practices of stewardship principles at the undergraduate and postgraduate medical education levels, particularly at the undergraduate level.[9] As a result, the literature surrounding how early antimicrobial stewardship

training starts in a physician's career, and whether teaching these principles from the outset is an effective strategy for combating antimicrobial resistance and lowering overall resistance rates remains unclear. To date, there have been few comprehensive evaluations of antimicrobial stewardship teaching programs and overall effectiveness of these training procedures in undergraduate medical institutions, and those that have been done are geographically restricted.[14] Accordingly, the extent to which this teaching translates into clinical practice is unclear. While recent studies identify the presence of stewardship curricula, the effectiveness of these interventions remains sparsely evaluated.[14-15] In light of clinical evidence, it is critical to understand the role that formal learning has to play in teaching prescription habits in order to change such behaviours. Furthermore, an understanding of the effectiveness of such teaching strategies is needed in order to understand its impact, if any, on clinical practice.

Despite the focus of ASP on physician education, antimicrobial prescribing is frequently designated to junior doctors and residents who may not have developed sufficient expertise on antimicrobials.[10,16] Furthermore, medical students have expressed interest in learning more about antimicrobials and their appropriate usage.[11-14,17,18] Many students recognize the growing problem of antibiotic overuse, and most would like more training in this area.[13-14,17-19] Students with formal training on antimicrobial stewardship, for example through didactic lectures with infectious disease specialists, feel better prepared for the practice and more comfortable with their knowledge.[11] However, studies suggest students predominantly have significant gaps in their knowledge regarding appropriate use of antimicrobials.[13,16-18,20-24] A number of studies have documented efforts of ASP for both undergraduate and postgraduate medical trainees.[9,25-28] Yet no consensus has been reached as to how to ensure students are invested in antimicrobial stewardship and how to ensure retention of this knowledge and clinical implementation. Teaching appropriate use of antimicrobials varies greatly between countries and programs.[9,14,29] A greater understanding of how these needs for ASP education are being addressed is an important next step towards addressing rising global awareness of the need for such principles in practice.

Despite student demand for learning on the topic of antimicrobial stewardship, and a focus on antimicrobial stewardship teaching at the physician level, it remains largely unknown at to the level of education at which medical trainees are first exposed to these concepts, how such principles are taught, and to what extent such teaching translates into clinical practice. We examined the published literature from 1946-2016 on antimicrobial stewardship for undergraduate and postgraduate medical trainees, including interventional design, how interventions were evaluated, and the effectiveness of the teaching strategies. We conducted a mapping review with the purpose of organizing what is known surrounding effective teaching on antimicrobial stewardship.[30] The review focused on the degree to which such interventions were evaluated to be able to make suggestions for further intervention adoption in medical education and to identify future areas of research. Given the heterogeneity of existing ASP research with respect to intervention type and evaluation, such mapping was valuable for examining the flexible implementation of interventions at the curricular level.[30] Our goal was to better understand the spectrum of teaching strategies employed in educating students on antimicrobial stewardship principles and practices, and to understand how such practices have been evaluated. By exploring this aim, stewardship programs and medical schools can use our findings to implement teaching methods that effectively educate medical students and result in lasting change in the clinical setting, thus helping inform future best practice and curriculum design. Furthermore, by exploring this aim, it is possible to discern trends in education practices, and identify gaps remaining in our understanding of how to educate trainees on antimicrobial stewardship in a way that results in lasting prescribing habits.

Methods

We conducted a literature review to compile a summary of the current published research on antimicrobial stewardship training in medical education. Ethical approval for this study was not deemed necessary, as our study constitutes a mapping review and did not involve primary data such as patient data collection or analysis.[30] A systemic map contextualizes a detailed systematic literature review and focuses on key characteristics of the literature, including study population and setting, and is therefore ideal for understanding the nature of ASP educational interventions in terms of trainee group and key intervention characteristics.[30,31]

Search strategy

We searched Ovid MEDLINE (1946 to 2016) and Ovid EMBASE (1947 to 2016), to identify research, review, and opinion articles addressing antimicrobial stewardship education for undergraduate and postgraduate medical trainees. Search strategies were developed by two authors (APA, EL). The authors translated the search strategies using each database platform's command language and the appropriate search fields. MeSH terms, EMTREE terms, and textwords were used for the search concepts of antibiotics, prescribing patterns, and medical education. The three concepts were combined with a Boolean "AND." No search limits were applied. Articles in English captured in EMBASE and MEDLINE were included in the final searches, which were completed in December 2016. We endeavoured to identify potential studies that were not captured from the database searches, by combing the reference lists of relevant

studies and reviews included in the full-text review. Grey literature was not included in the search.

Article selection

Our database searches identified 4385 articles with potential relevance to our study. Three authors (SS, VZ, DC) identified the relevant articles for full-text review by examining the titles and abstracts of the articles identified in the database searches. We included articles written in English that discussed the use of antimicrobial stewardship in medical education. Articles that mentioned solely physician education, continuing education, or public education were excluded. Articles related to non-medical health professions education were also excluded as we focused on medical professionals in this review. Articles that discussed resource management, rational prescribing, or antimicrobials but did not discuss stewardship principles (for example, antimicrobial teaching focused on drug indications and dosing) were also excluded. Lastly, articles that identified only the problem (without discussion of any solution) or articles that did not discuss a specific intervention were excluded. Any disagreements between reviewers were brought to another author (FF), who resolved the dispute. After title and abstract screening, 227 articles were selected for full-text review. After the exclusion criteria were applied, 42 articles satisfied the inclusion criteria (see Figure 1). Searching the reference lists of the 42 included articles identified six additional studies for inclusion, for a total of 48 articles. For a complete list of all included articles, see Appendix.

Each article included for full-text review was independently reviewed by two authors (two of SS, DC, VZ). The authors abstracted the following data fields from the included articles: authors, title, journal, year of publication, location, intervention, purpose of intervention, study design, participants, outcomes, key findings, and the level of evaluation from Kirkpatrick's evaluation of education model:32 (1) reaction (satisfaction or happiness; what participants thought of the educational intervention), (2) learning (change in attitude and/or knowledge or skills gained assessed by test or demonstration), (3) behaviour (transfer of attitude, knowledge and/or skills to workplace or clinical setting, for example, determined through observation), and (4) results (patient care affected or societal impact due to participation in the educational intervention evaluated by looking at patient outcomes, for example).

Results

Four types of articles were included in this mapping review: (1) commentaries/perspectives encompassing editorials and letters, some of which briefly discussed evaluations that had been done; (2) program descriptions without evaluation or outcomes measured; (3) review articles; and (4) research or evaluation articles with clear study design descriptions and outcomes. Across our dataset, there were nine perspective pieces,[25,33-34,39,41,44,47,60,68] three program descriptions,[28,43,70] five review articles,[42,45-46,52,71] and 31 research articles.[9,15-18,24,29,35-38,40,48-51,53-59,61-67,69]

Target learner group

Of the 48 articles included in this summary, 14 included only undergraduate medical trainees,[9,17,18,24,25,26,33-40] 11 included both undergraduate and postgraduate trainees,[29,41-50] 20 included only postgraduate trainees,[15,16,51-68] and three did not specify the training level of the participants (see Table 1).[69-71] The location of the studies also varied; the majority of studies were situated in Europe (20 studies; 41.7%), and 16 (33.3%) studies were based in the United Kingdom. Further, eleven articles (22.9%) took place in North America, three (6.3%) in Australia, eight (16.7%) in different Asian countries and two individual studies were conducted in South America and South Africa respectively. Four review articles included articles with geographical diversity.

Intervention design

The types of interventions varied widely amongst studies and schools. Approaches at the undergraduate level (as demonstrated in detail in Appendix) included didactic teaching,[9,25,29,36,40,44,50] web-based teaching,[39] clinical case discussions,[35] workshops/seminars,[26,34,69] board games,[37-38] guideline promotion,[35,49-59] audits on current stewardship integration in the medical curriculum,[17-18,24] and intensive modules,[47] often in combination. Didactic teaching was moderately emphasized on the whole. Studies that examined educational interventions comparatively between medical institutions noted a widespread array of teaching strategies employed. These studies noted an overall inconsistency of trainees' exposure to stewardship topics and of the intervention's emphasis.[17-18]

Interventions aimed at the postgraduate level were similarly varied, and can be explored in Appendix. These studies focused on providing feedback to students in relation to current prescribing practices rather than teaching new skills. Many methods provided resources for residents to consult and use to make prescribing choices and influence behaviours, or focused on identifying gaps in trainees' knowledge and practice with the goal of rectifying their practice in the future. These approaches included: web-based tutorials,[47,67] workshops,[57,62,65-66] lectures and information sessions,[49,52,58,61-62] using a restricted list of antibiotics to promote compliance with guidelines,55,58 audits followed by feedback,[15-16,52,56,60,64,67-68] chart reviews and feedback,[51,58-59,66] augmented reality,[53] viral surveillance program,[61] using special prescribing pads,[54] integration of social media platforms such as Twitter and Facebook,[67] consulting specialists to improve compliance with guidelines,[48,52,57,63,66-67] and consulting guidelines or written information.[44,50,52,56-57,62,71] Many interventions included a combination of these tactics. Interestingly, we found that auditing techniques evaluating prescribing tendencies was implemented at the

Table 1. Articles that reported evaluations from each level of Kirkpatrick's evaluation of education model, by intervention target group

Level of trainees	No evaluation	Kirkpatrick Level 1 (Reaction)	Kirkpatrick Level 2 (Learning)	Kirkpatrick Level 3 (Behaviour)	Kirkpatrick Level 4 (Results)
Undergraduate medical education	Davenport et al. 2005,[35] Kerr et al. 2001,[33] Luther, Ohl and Hicks 2013,[25] Pulcini et al. 2015,[9] Shankar et al. 2011,[26] Wright and Jain 2004[34]	Beylefeld and Struwig 2007,[38] Chuenchom, et al. 2016,[17] Haque et al. 2016,[18] Hoque, Mostafa & Haque, 2016,[24] Marwick and Nathwani 2007,[39] Minen et al. 2010,[36] Valente et al. 2009[37]	Huang et al. 2013,[40] Marwick and Nathwani, 2007,[39] Valente et al. 2009[37]		
Postgraduate medical education	Brennan and Mattick 2013,[52] Philp, Wilford and Low 1986[51]	Bannan et al. 2009,[55] Gharbi et al. 2016,[16] Nifakos, Tomson and Zary 2014,[53] Nand et al. 2016,[68] Temte et al. 1999,[61] Welch et al. 2000[54]	Faryna, Wegowske and Goldenberg 1987,[56] Feucht et al. 2003,[57] Ikai et al. 2012,[58] Pisano et al. 2016,[67] Rawson et al. 2016[15]	Légaré et al 2011,[59] Irfan et al. 2015,[65] Main and Koerner 2012,[60] McLellan et al. 2016,[66] Temte et al. 1999,[61] Welch et al. 2000,[54] Zwar, Gordon and Sanson-Fisher 1995,[62] Zwar et al. 1999,[63] Lee et al. 2014[64]	
Mixed undergraduate and postgraduate medical education	Davey et al 1993,[29] Ghafur 2013,[41] Greenwood 1998,[44] Lee et al. 2013,[45] Lee et al. 2015,[46] McNulty, Cookson and Lewis 2012,[43] Pulcini and Gyssens 2013[42]		Dawson, Bennett and Ongley, 2010,[47] Zamin, Pitre and Conly, 1997[48]	De Souza et al. 2006,[50] Thamlikitkul et al. 1998[49]	Thamlikitkul et al. 1998[49]
Unspecified	Davey et al. 2007,[71] Le Normand et al. 1994[69]		Bain 1984[70]		

Table 2. Types of Interventions and their Kirkpatrick Level of Evaluation[*†]

Level of trainees	No Evaluation	Kirkpatrick Level 1	Kirkpatrick Level 2	Kirkpatrick Level 3	Kirkpatrick Level 4
Undergraduate	Didactic teaching (4) Workshop/seminar (3) Clinical case discussion (1) Guideline promotion (1)	Didactic teaching (1) Board game (1) Audit (3)	Didactic teaching (1) Web-based teaching (1) Board game (1) Intensive module (1)	Guideline promotion (2) Didactic teaching (1)	
Postgraduate	Specialist consult (3) Guideline use (2) Didactic teaching (1) Audit (1) Chart review (1)	Restricted antibiotic list (1) Augmented reality (1) Audit (2)	Guideline use (2) Specialist consult (3) Web-based teaching (2) Workshops (1) Didactic teaching (1) Chart review (1) Restricted antibiotic list (1) Audit (3) Social media & online education (1)	Didactic teaching (2) Audit (2) Guideline use (3) Specialized prescribing pads (1) Viral surveillance program (1) Specialist consult (3) Chart Review (3) Workshops (3)	Didactic teaching (1)

[*]Numbers reflect the number of different studies employing each intervention type
[†]Some studies used more than one type of intervention, or the same intervention in both undergraduate and postgraduate students, but specific interventions are listed separately

postgraduate level, but not in undergraduate medical education settings.

Outcomes (variables of interest)

Studies measured a wide variety of outcomes (see Appendix for full list of variables of interest). Although it was clear from the studies included in this review that medical students required supplementary antimicrobial education and desired their curricula to be augmented, all but one of the articles that measured outcomes (Kirkpatrick's Levels 1-4) reported that the intervention made a difference. Notably, one exception we identified was an article by De Souza et al., which evaluated the current medical curricula from an ASP perspective, but did not involve a more specifically active intervention.[50] Additionally, all studies that evaluated outcomes on a Kirkpatrick Level 1 scale supported sentiments echoed in the literature that, despite resources available in hospital or knowledge gained through the intervention, trainees do not feel comfortable with their knowledge. In studies evaluating behavioural change (Kirkpatrick Level 3-4), most outcomes included rates of prescriptions (total and/or inappropriate prescriptions), and fewer directly evaluated patient safety or cost parameters. In studies that evaluated knowledge (Kirkpatrick Level 2),

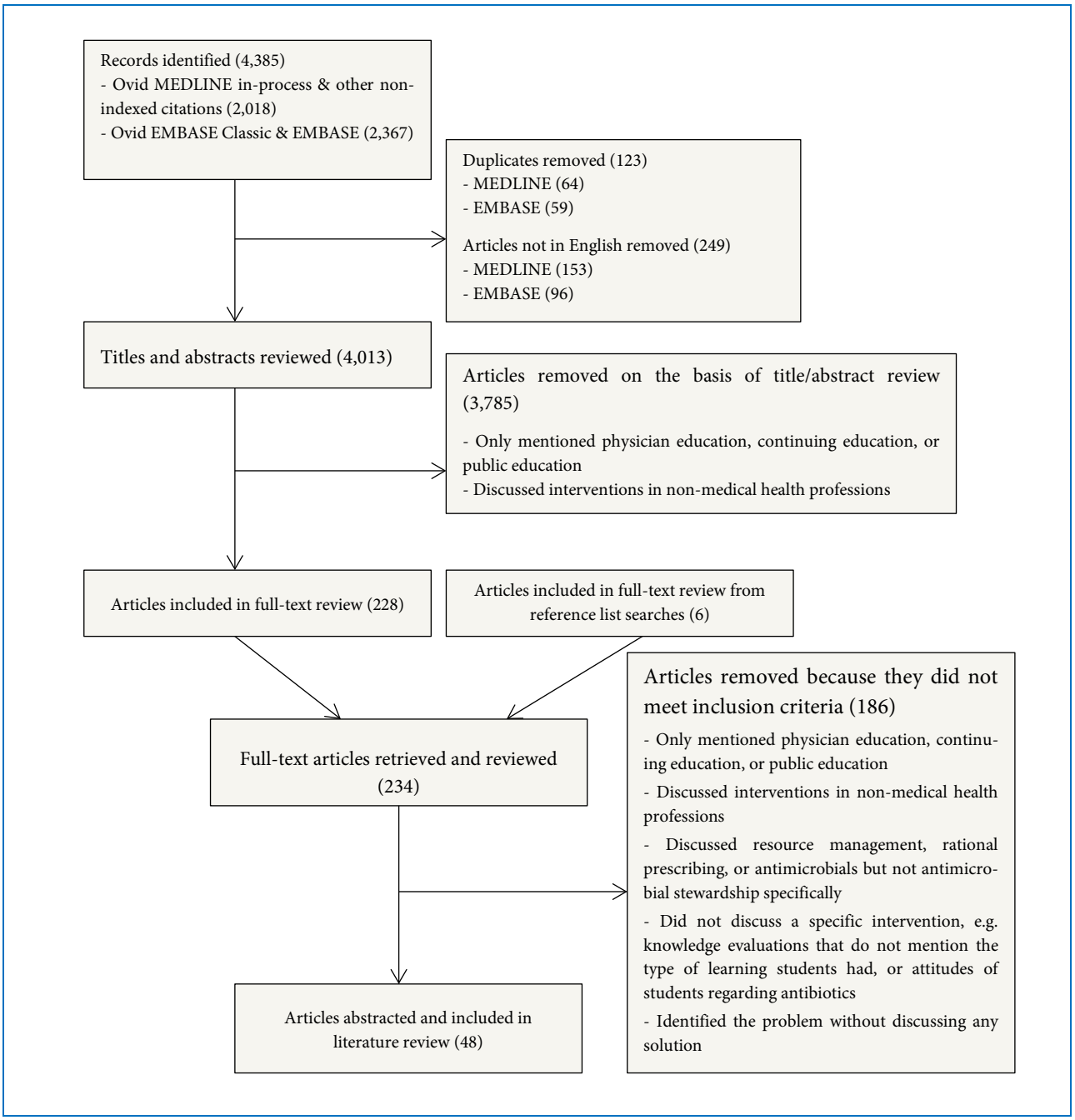

Figure 1. Search Strategy Flow Chart

there was variability between those evaluating students' knowledge of stewardship principles and those evaluating the application of such principles to sample cases in a controlled setting.

Evaluations

Over half (n=31, 64.6%) of the 48 studies included in this review reported that interventions were evaluated in some capacity. Eleven (22.9%) articles reported on a Kirkpatrick Level 3 or 4 (behaviour) evaluation of the intervention,[49-50,54,59-66] eleven (22.9%) reported on a knowledge evaluation (Kirkpatrick Level 2),[15,37,39-40,47-48,56-58,67,70] nine (18.8%) reported only an evaluation of participants' reactions (Kirkpatrick Level 1),[16-18,24,36,38,53,55,68] and 17 (35.4%) reported no evaluation of the intervention at all.[9,25,26,29,33-35,41-46,51-52,69,71] Of those evaluating behaviour, no articles reported long-term behaviour changes after the intervention was completed, as only pre- and post-intervention evaluations were conducted. Of interventions that were evaluated, a mix between summative and mixed summative/formative evaluations was conducted. None of the articles that targeted undergraduate medical students evaluated whether the intervention influenced their prescribing behaviour either as a senior medical student or followed them beyond graduation (see Table 1). No undergraduate evaluations were followed up by further postgraduate evaluations, and no undergraduate articles examined the longitudinal effect of the measured intervention on future practice.

Additionally, more individualized teaching methods, such as audits, consults, and chart reviews were more frequently evaluated at a higher Kirkpatrick level, while workshops and didactic teaching, interventions that often occurred in larger groups rather than one-on-one, were generally not evaluated at a high level (see Table 2).

Discussion

In this review, we found a myriad of training approaches to antimicrobial stewardship in undergraduate and postgraduate medical education. While our understanding of antimicrobial resistance has grown, our understanding of effective educational approaches on the topic has not. Approximately one quarter of educational interventions evaluated behaviour change (Kirkpatrick Level 3), and of these, only two articles that included undergraduate education evaluated interventions at this level. Further, studies frequently did not proceed to evaluate interventions at all. There continues to be a dearth of information available as to whether the effects measured by the studies that did evaluate their outcomes last beyond the immediate intervention time frame. The long-term effects of these educational interventions are unknown as the studies we identified largely do not include follow-up. It remains unclear whether these identified interventions are effective, more broadly, at influencing physician behaviour. In order to change the prescribing habits of future physicians and to lower antimicrobial resistance rates by teaching trainees best practices, more robust evaluations of innovative teaching strategies are needed. Many studies included in this review (n=17), did not evaluate the teaching strategies employed by respective investigators; instead, they simply reported on implementation. Evidence-based curriculum development is integral in the facilitation of best clinical practices. Medical educators and researchers must rigorously evaluate the efficacy of new educational interventions.[72] Particularly in the undergraduate medical setting, it is invaluable to understand whether teaching about appropriate use of antimicrobials is retained by students as they go out to practice. We must understand whether interventions can be effectively applied at this level to influence prescribing behaviour on a long-term basis (i.e., Kirkpatrick Level 3), which will be instrumental in facilitating better patient care and societal impacts collectively (i.e., Kirkpatrick Level 4).

With antimicrobial resistance a growing global concern, there have been calls for further integration of teaching on this topic at the undergraduate medical level.[42] Pulcini et al. identified physicians' lack of knowledge of infectious diseases and antibiotics as a cause of their inappropriate prescribing,[28] and both Pulcini et al. and Davey et al. recommended the translation of prescribing principles into learning topics and competencies for undergraduate core curricula.[29,42] Our results support the findings of the Infectious Diseases Society of America that education on appropriate antimicrobial prescribing is highly variable across training facilities in the United States.[73] In addition, similar inconsistencies in training seen on a global scale. Several recent studies conducted in the United Kingdom show that educational standards concerning antimicrobial stewardship vary greatly between postgraduate curricula, and provide further evidence that such inconsistent standards are a problem globally.[73] To identify which of these educational interventions is most effective in bolstering medical student's antimicrobial knowledge, our study shows that further evaluations of current approaches are needed. Once effective training programs are identified, such programs should then be expanded across undergraduate medical curricula. Recent changes to the Leader role in the CanMEDS 2015 physician competency framework, emphasizing quality improvement and patient safety,[74] align with the appraisal of antimicrobial stewardship required at the undergraduate level. CanMEDS is a framework that outlines requisite competencies physicians need to successfully enact in order to meet the health care needs of the individuals and groups they serve. One of the competencies of the Leader role is that a physician must "engage in the stewardship of health care resources".[74] With this objective in mind, developing antimicrobial resistance education at the undergraduate level and evaluating such strategies to better educate future physicians fits well with the CanMEDS framework.

The educational interventions included in this review were highly varied, and different interventions were often

used in different combinations. This practice of trying various strategies reflects the directive, led by Julio Frenk and Lincoln Chen, necessitating transformative and creative teaching initiatives.[75] However, the included articles also span many decades and demonstrate little forward momentum towards improving and implementing ideas that have been shown to be promising in the past. While there is a great need for innovation and for the development of new ideas, there is no need to re-invent the wheel. More research must be executed to build on existing interventions and design effective learning programs. Collaboration between medical schools and the breakdown of institutional barriers (i.e. sharing best educational practices) can help accelerate this development process. Sharing resources and learning across institutions, as described by Frenk et al.,[75] is integral to moving forward, but it also requires stringent evaluation metrics to assess collaborations and new educational interventions.

Finally, it remains unclear as to the extent that antimicrobial stewardship is actually incorporated into undergraduate medical curricula, particularly in different settings globally. Future research should target the extent and nature of these stewardship programs and must evaluate their overall effectiveness.

Due to the nature of our study, there are certain limitations to the interpretation of our results. Our review discusses the available English-language published literature, and does not capture studies that have been exclusively published in other languages. Thus, our findings might reflect the stewardship practices of the English-speaking world more heavily. However, considering the geographical diversity in the included studies, our findings are likely generalizable (on an international scale). In addition, we conducted our literature search through peer-reviewed journal articles indexed in two databases, excluding other databases. Other program descriptions and practices existing outside of peer-reviewed journal articles (e.g., grey literature or book chapters) were not included in this review; these bodies of literature are unlikely to include evaluations of antimicrobial stewardship interventions and were deemed outside of this study's scope. However, the exclusion of grey literature from this review may limit our understanding of global trends due to the lack of published evaluation of such medical curricula. Finally, our review focused entirely on medical prescribers at the trainee level, and therefore the role of other health care professionals in antimicrobial stewardship practices was not included. These allied health professionals play a significant role in antimicrobial stewardship, particularly in jurisdictions where autonomous prescribing capabilities are authorized. However, comparing medical training with other health professional fields, and evaluating stewardship training in each profession's curricula, are difficult to compare due to their vastly different structure and outside this study's scope.

Conclusions

Although our understanding of the scope of antimicrobial resistance has progressed, our understanding of which educational approaches to antimicrobial stewardship are effective has not. As physicians strive towards evidence-informed education, we need an evidence base that captures the impact of such programs on trainees' prescribing behaviour after graduation. Currently, there are no best practice or national guidelines for teaching antimicrobial stewardship in undergraduate and postgraduate medical education. However, our study demonstrates that medical schools worldwide are supporting multitudinous antimicrobial stewardship interventions. It is possible that many intervention designs result in the desired outcome, simply by trainees' attention to this area of interest. If so, there is an opportunity to optimize learning outcomes and intervention efficiency. Yet if such gains are short-lived and not habit forming, we must return to the drawing board to once again target prescribing habits in a new manner. Are we wasting resources and supporting ineffective interventions that are not cost-effective? Are we wasting time and trusting that these interventions will lead to a future culture of stewardship? Further rigorous evaluation of existing programs that capture Kirkpatrick Levels 3 and 4 are necessary to answer these questions, and thereby encourage additional medical education programs to incorporate such practices into their curricula. In order to foster a culture of stewardship amongst our trainees, we must develop and assess proficient educational interventions.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. Dellit TH, Owens RC, McGowan JE, Gerding DN, Weinstein RA, Burke JP, et al. Infectious diseases society of America and the society for healthcare epidemiology of America guidelines for developing an institutional program to enhance antimicrobial stewardship. Clin Infect Dis. 2007;44:159–177.

2. Costelloe C, Metcalfe C, Lovering A, Mant D, Hay AD. Effect of antibiotic prescribing in primary care on antimicrobial resistance in individual patients: systematic review and meta-analysis. BMJ. 2010;340:c2096.

3. De Santis G, Harvey KJ, Howard D, Mashford ML, Moulds RF. Improving the quality of antibiotic prescription patterns in general practice. The role of educational intervention. Med J Aust. 1994;160:502-505.

4. Cooper BS, Stone SP, Kibbler CC, Cookson BD, Roberts JA, Medley GF et al. Systematic review of isolation policies in the hospital management of methicillin-resistant Staphylococcus aureus: a review of the literature with epidemiological and economic modelling. Health Technol Assess. 2003;7:1-194.

5. Cooper BS, Stone SP, Kibbler CC, Cookson BD, Roberts JA, Medley GF, et al. Isolation measures in the hospital management of methicillin resistant Staphylococcus aureus (MRSA): systematic review of the literature. BMJ. 2004;329:533.

6. Davey P, Brown E, Charani E, Fenelon L, Gould IM, Holmes A, et al. Interventions to improve antibiotic prescribing practices for hospital inpatients. Cochrane Database Syst Rev. 2013;4:CD003543.

7. Davey P, Brown E, Fenelon L, Finch R, Gould I, Holmes A, et al. Systematic review of antimicrobial drug prescribing in hospitals. Emerg Infect Dis. 2006;12:211-216.

8. Roumie CL, Halasa NB, Edwards KM, Zhu Y, Dittus RS, Griffin MR. Differences in antibiotic prescribing among physicians, residents, and nonphysician clinicians. Am J Med. 2005;118:641–648.

9. Pulcini C, Wencker F, Frimodt-Møller N, Kern WV, Nathwani D, Rodriguez-Baño J, et al. European survey on principles of prudent antibiotic prescribing teaching in undergraduate students. Clin Microbiol Infect. 2015;21(4):354-361.

10. Charani E, Cooke J, Holmes A. Antibiotic stewardship programmes—what's missing? J Antimicrob Chemother. 2010;65:2275–2277.

11. Abbo LM, Cosgrove SE, Pottinger PS, Pereyra M, Sinkowitz-Cochran R, Srinivasan A, et al. Medical students' perceptions and knowledge about antimicrobial stewardship: how are we educating our future prescribers? Clin Infect Dis. 2013;57(5):631-638.

12. Pulcini C, Williams F, Molinari N, Davey P, Nathwani D. Junior doctors' knowledge and perceptions of antibiotic resistance and prescribing: a survey in France and Scotland. Clin Microbiol Infect. 2011;17(1):80-87.

13. Dyar OJ, Howard P, Nathwani D, Pulcini C. Knowledge, attitudes, and beliefs of French medical students about antibiotic prescribing and resistance. Med Maladies Infect. 2013;43(10):423-430.

14. Castro-Sánchez E, Drumright LN, Gharbi M, Farrell S, Holmes AH. Mapping Antimicrobial Stewardship in Undergraduate Medical, Dental, Pharmacy, Nursing and Veterinary Education in the United Kingdom. PloS One. 2016;11(2):e0150056.

15. Rawson TM, Butters TP, Moore LS, Castro-Sánchez E, Cooke FJ, Holmes AH. Exploring the coverage of antimicrobial stewardship across UK clinical postgraduate training curricula. J Antimicrob Chemother. 2016;71(11):3284-3292.

16. Gharbi M, Moore LS, Castro-Sánchez E, Spanoudaki E, Grady C, Holmes AH, et al. A needs assessment study for optimizing prescribing practice in secondary care junior doctors: The Antibiotic Prescribing Education among Doctors (APED). BMC Infect Dis. 2016;16(1):456.

17. Chuenchom N, Thamlikitkul V, Chaiwarith R, Deoisares R, Rattanaumpawan P. Perception, attitude and knowledge regarding antimicrobial resistance, appropriate antimicrobial use and infection control among future medical practitioners: A multicenter study. Infect Control Hosp Epidemiol. 2016;37(5):603-605.

18. Haque M, Rahman NI, Zulkifli Z, Ismail S. Antibiotic prescribing and resistance: Knowledge level of medical students of clinical years of university Sultan Zainal Abidin, Malaysia. Ther Clin Risk Manag. 2016;12:413-426.

19. Ibia E, Sheridan M, Schwartz R. Knowledge of the principles of judicious antibiotic use for upper respiratory infections: a survey of senior medical students. South Med J. 2005;98(9):889-896.

20. Dyar OJ, Pulcini C, Howard P, Nathwani D. European medical students: a first multicentre study of knowledge, attitudes and perceptions of antibiotic prescribing and antibiotic resistance. J Antimicrob Chemother. 2014;69:842–846.

21. Humphreys H, Dillane T, O'Connell B, Luke LC. Survey of recent medical graduates' knowledge and understanding of the treatment and prevention of infection. Irish Med J. 2006;99(2):58-59.

22. Jamshed SQ, Elkalmi R, Rajiah K, Al-Shami AK, Shamsudin SH, Siddiqui MJ, et al. Understanding of antibiotic use and resistance among final-year pharmacy and medical students: a pilot study. J Infect Dev Ctries. 2014;8(6):780-785.

23. Khan A K A, Banu G, K K R. Antibiotic Resistance and Usage-A Survey on the Knowledge, Attitude, Perceptions and Practices among the Medical Students of a Southern Indian Teaching Hospital. J Clin Diagn Res. 2013; 7(8):1613-6.

24. Hoque R, Mostafa A, Haque M. Insight of medical students of clinical years to antimicrobials prescribing and resistance in private medical school, Chittagong, Bangladesh. Journal of Young Pharmacists. 2016; 8(4):447-455.

25. Luther VP, Ohl CA, Hicks LA. Antimicrobial stewardship education for medical students. Clin Infect Dis. 2013;57(9):1366.

26. Shankar PR, Bajracharya O, Jha N, Gurung SB, Singh KK. Teaching medical students to use antibiotics rationally in a medical school in Nepal. Edu Med J. 2011;2(10):WMC002329.

27. D Walker, T Fowler, editors. Annual report of the Chief Medical Officer. Volume 2. Infections and the rise of antimicrobial resistance. Department of Health; 2011 [cited 14 Oct 2017]; Available from: http://media.dh.gov.uk/network/357/files/2013/03/CMO-Annual-Report-Volume-2-20111.pdf.

28. Moody J, Cosgrove SE, Olmsted R, Septimus E, Aureden K, Oriola S, et al. Antimicrobial stewardship: a collaborative partnership between infection preventionists and healthcare epidemiologists. Infect Control Hosp Epidemiol. 2012;33:328–330.

29. Davey P, Hudson S, Ridgway G, Reeves D. A survey of undergraduate and continuing medical education about antimicrobial chemotherapy in the United Kingdom. British society of antimicrobial chemotherapy working party on antimicrobial use. Br J Clin Pharmacol. 1993;36:511–9.

30. Grant MJ, Booth A. A typology of reviews: an analy-sis of 14 review types and associated methodologies. Health Info Libr J. 2009; 26(2):91-108.

31. Cooper ID. What is a "mapping study?" J Med Libr Assoc. 2016;104(1), 76–78.

32. Kirkpatrick DL. Evaluation of training. In: Craig R, Bittel I, editors. Training and Development Handbook. First edition. New York: McGraw-Hill; 1967.

33. Kerr KG, Ottery C, Hawkey PM, Roberts TE. The teaching of appropriate use of antimicrobials. Lancet. 2001;358(9299):2173-2174.

34. Wright EP, Jain P. Survey of antibiotic knowledge amongst final year medical students. J Antimicrob Chemother. 2004;53(3):550-551.

35. Davenport LA, Davey PG, Ker JS, BSAC Undergraduate Education Working Party. An outcome-based approach for teaching prudent antimicrobial prescribing to undergraduate medical students: report of a Working Party of the British Society for Antimicrobial Chemotherapy. J Antimicrob Chemother. 2005; 56(1):196-203.

36. Minen MT, Duquaine D, Marx MA, Weiss D. A survey of knowledge, attitudes, and beliefs of medical students concerning antimicrobial use and resistance. Microb Drug Resist. 2010;16(4):285-9.

37. Valente P, Lora PS, Landell MF, Schiefelbein CS, Girardi FM, Souza Ldos R, et al. A game for teaching antimicrobial mechanisms of action. Med Teach. 2009;31(9):e383-392.

38. Beylefeld AA, Struwig MC. A gaming approach to learning medical microbiology: students' experiences of flow. Med Teach. 2007;29(9):933-40.

39. Marwick CA, Nathwani D. Improving antimicrobial prescribing through knowledge and skills. J Antimicrob Chemother. 2007;59(4):819-20.

40. Huang Y, Gu J, Zhang M, Ren Z, Yang W, Chen Y, et al. Knowledge, attitude and practice of antibiotics: a questionnaire study among 2500 Chinese students. BMC Med Educ. 2013;13(1):1.

41. Ghafur A. India must overhaul medical training to act on antimicrobial resistance. BMJ. 2013;347:f4230.

42. Pulcini C, Gyssens IC. How to educate prescribers in antimicrobial stewardship practices. Virulence. 2013;4(2):192-202.

43. McNulty CA, Cookson BD, Lewis MA. Education of healthcare professionals and the public. J Antimicrob Chemother. 2012; 67 Suppl 1:i11-8.

44. Greenwood D. Resistance to antimicrobial agents: a personal view. J Med Microbiol. 1998;47(9):751-755.

45. Lee CR, Cho IH, Jeong BC, Lee SH. Strategies to minimize antibiotic resistance. Int J Environ Res Pub Heal. 2013;10(9):4274-4305.

46. Lee CR, Lee JH, Kang LW, Jeong BC, Lee SH. Educational effectiveness, target, and content for prudent antibiotic use. Biomed Res Int. 2015;2015:214021

47. Dawson SJ, Bennett H, Ongley V. E-learning module for delivering infection prevention and control training. J Hosp Infect. 2010;76(1):89-90.

48. Zamin MT, Pitre MM, Conly JM. Development of an intravenous-to-oral route conversion program for antimicrobial therapy at a Canadian tertiary care health facility. Ann Pharmacother. 1997;31(5):564-570.

49. Thamlikitkul V, Danchaivijitr S, Kongpattanakul S, Ckokloikaew S. Impact of an educational program on antibiotic use in a tertiary care hospital in a developing country. J Clin Epidemiol. 1998;51(9):773-778.

50. De Souza V, MacFarlane A, Murphy AW, Hanahoe B, Barber A, Cormican M. A qualitative study of factors influencing antimicrobial prescribing by non-consultant hospital doctors. J Antimicrob Chemother. 2006;58(4):840-843.

51. Philp JR, Wilford RJ, Low IW. Implications for medical education of nonrational prescribing by residents. Acad Med 1986;61(5):418-420.

52. Brennan N, Mattick K. A systematic review of educational interventions to change behaviour of prescribers in hospital settings, with a particular emphasis on new prescribers. Brit J Clin Pharmaco. 2013;75(2):359-372.

53. Nifakos S, Tomson T, Zary N. Combining physical and virtual contexts through augmented reality: design and evaluation of a prototype using a drug box as a marker for antibiotic training. PeerJ. 2014;2:e697.

54. Welch SA, Novy M, Preisz P, Quinn DI, Whicker SD, Brown SE, et al. Promoting rational prescribing by emergency department junior medical officers. Aust J Hosp Pharm. 2000;30(6):262-267.

55. Bannan A, Buono E, McLaws ML, Gottlieb T. A survey of medical staff attitudes to an antibiotic approval and stewardship programme. Intern Med J. 2009;39(10):662-668.

56. Faryna A, Wergowske GL, Goldenberg K. Impact of therapeutic guidelines on antibiotic use by residents in primary care clinics. J Gen Intern Med. 1987;2(2):102-107.

57. Feucht CL, Rice LB. An interventional program to improve antibiotic use. Ann Pharmacother. 2003;37(5):646-651.

58.Ikai H, Morimoto T, Shimbo T, Imanaka Y, Koike K. Impact of post-graduate education on physician practice for community-acquired pneumonia. J Eval Clin Pract. 2012;18(2):389-395.

59.Légaré F, Labrecque M, Godin G, LeBlanc A, Laurier C, Grimshaw J, et al. Training family physicians and residents in family medicine in shared decision making to improve clinical decisions regarding the use of antibiotics for acute respiratory infections: protocol for a clustered randomized controlled trial. BMC Fam Pract. 2011;12:3.

60.Main B, Koerner RJ. The medical educators' contribution to curtailing antimicrobial resistance. J Grad Med Ed. 2012;4(3):392.

61. Temte JL, Shult PA, Kirk CJ, Amspaugh J. Effects of viral respiratory disease education and surveillance on antibiotic prescribing. Fam Med. 1999;31:101-106.

62.Zwar NA, Gordon JJ, Sanson-Fisher RW. Evaluation of an educational program in rational prescribing for GP trainees. Aust Fam Physician. 1995;24(5):833-838.

63. Zwar N, Wolk J, Gordon J, Sanson-Fisher R, Kehoe L. Influencing antibiotic prescribing in general practice: a trial of prescriber feedback and management guidelines. Fam Pract. 1999;16(5):495-500.

64. Lee TC, Frenette C, Jayaraman D, Green L, Pilote L. Antibiotic self-stewardship: trainee-led structured antibiotic time-outs to improve antimicrobial use. Ann Intern Med. 2014; 161 Suppl 10:S53-8.

65. Irfan N, Brooks A, Mithoowani S, Celetti SJ, Main C, Mertz D. et al. A controlled quasi-experimental study of an educational intervention to reduce the unnecessary use of antimicrobials for asymptomatic bacteriuria. PLoS One. 2015;10(7):e0132071.

66. McLellan L, Dornan T, Newton P, Williams SD, Lewis P, Steinke D, et al. Pharmacist-led feedback workshops increase appropriate prescribing of antimicrobials. J Antimicrob Chemother. 2016;71(5):1415-1425.

67. Pisano J, Pettit N, Bartlett A, Bhagat P, Han Z, Liao C. Social media as a tool for antimicrobial stewardship. Am J Infect Control. 2016;44(11):1231-1236.

68. Nand P, Wilson MD, Cohen SH, Brown J. Curbing antimicrobial resistance: Do physicians receive adequate education about antibiograms? J Infect. 2016;72(1):127-129.

69. Le Normand Y, Drugeon HB, Potel G, Kergueris MF, Raffi F, Milpied N, et al. Teaching individualized antibiotic dosage regimens by means of two computer-assisted learning programs. Int J Biomed Comput. 1994;36(1):117-119.

70. Bain DJ. Practice research. Training for general practice: clinical behaviour in trainers and trainees. Br Med J (Clin Res Ed).1984;288(6419):762-764.

71. Davey P, Garner S. Professional education on antimicrobial prescribing: a report from the Specialist Advisory Committee on Antimicrobial Resistance (SACAR) Professional Education Subgroup. J Antimicrob Chemother. 2007; 60 Suppl 1:i27-32.

72. Lodico MG, Spaulding DT, Voegtle KH. Methods in educational research: from theory to practice. John Wiley & Sons; 2010.

73. Infectious Diseases Society of America (IDSA), Spellberg B, Blaser M, Guidos RJ, Boucher HW, Bradley JS, et al. Combating antimicrobial resistance: policy recommendations to save lives. Clin Infect Dis. 2011;52 Suppl 5:S397-428.

74. Frank JR, Snell L, Sherbino J, editors. CanMEDS 2015 Physician competency framework. Ottawa: Royal College of Physicians and Surgeons of Canada; 2015.

75. Frenk J, Chen L, Bhutta ZA, Cohen J, Crisp N, Evans T, et al. Health professionals for a new century: transforming education to strengthen health systems in an interdependent world. Lancet. 2010;376(9756):1923-1958.

Appendix A

Studies with antimicrobial stewardship medical education interventions

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
Brennan and Mattock, 2013	Review N/A	N/A	Intervention types include: educational materials, conferences and training, audit and feedback, outreach visits, reminders, marketing, patient-mediated interventions, and use of a local opinion leader. Most interventions used more than one strategy.	Residents and young doctors. Young prescribers in other health professions	A variety of outcome measures have been used, most commonly rates of appropri-ate/inappropriate prescribing	Most interventions were effective. No firm conclusions can be drawn about the most effective type of intervention, as some studies found one strategy effective while others found the same one ineffective.	No evaluation
Daven-port et al, 2005	Research United Kingdom	To understand outcome-based education and how it has been applied and then been implemented in regards to antimicrobial prescribing	A resource template for teaching prudent prescribing included: (i) standardized vignettes covering the 12 learning outcome domains; (ii) a reflective patient record book, including a personal antibiotic formulary; (iii) discussion session guidelines; (iv) prescribing exercises; and (v) a support resource pack.	Medical students	Prescribing patterns	Educational approaches should strive to achieve predetermined outcomes and the intervention should be used in curricula	No evaluation
Davey et al, 2007	Review United Kingdom	To press for greater coverage of prudent antimi-crobial use in undergraduate and postgraduate curricula; to lead in better integra-tion of antimicro-bial teaching in a variety of settings	Specialist Advisory Committee on Antimicrobial Resistance evaluating educational approaches	N/A	Attitudes and belief post ASP intervention through ques-tionnaire, number of requests for restricted antibiotics	Hospitals continue to use different metrics in surveillance but are eager to collaborate. The SACAR Initiative has established a framework for UK collaboration on multi-disciplinary education that will define learning outcomes for all health professionals.	No evaluation
Davey et al, 1993	Research United Kingdom	To examine methods of determining and influencing antimicrobial use in the UK - specifically, evaluating undergraduate and postgraduate education on antimicrobial chemotherapy to establish what info is available and amount and content of the education	Questionnaires evaluating undergraduate and postgradu-ate curricula; undergraduate teaching mostly lecture based, postgraduate included consulting specialists and using material from drug infor-mation centres	Medical students and residents	What are the main factors that influence prescribing behaviour	The median amount of core undergraduate teaching was 13.5h but with a wide range. Content was oriented towards drugs rather than diseases. Most teaching was by formal lecture as part of a core programme. Postgradu-ate: advice from specialists and requests from practitioners most important determinants of content. Information from drug info centres discussed drugs not diseases. Knowledge should be disseminated through local networks of practitioners; all doctors require education; need national coordination of information dissemination	No evaluation

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
Ghafur 2013	Opinion India	To reduce resistance rates and treat bacterial infections; to develop a functioning policy for antibiotics use and infrastructure for infection control	Curriculum must be revised to be less didactic, focus more on diseases of the tropics, rational antibiotics usage, and infection control.	Medical students and postgraduate trainees	N/A	Incorporate more infectious disease training in all major teaching hospitals; more clinically oriented basic science training	No evaluation
Green-wood, 1998	Opinion United Kingdom	Antimicrobial resistance is a growing problem that must be curtailed; in order for antimicrobial chemotherapy to have a secure future, prescribers must learn to use these tools with greater discretion	Teaching in the UK is spasmodic. Nottingham offers a 2-week module on antimicrobial therapy for third year students. Most schools: a few lectures on principles, and practical prescribing should be learnt at the bedside. Postgraduate: little is done.	Medical students and residents	Hours and types of hours spent in undergraduate and postgraduate settings	Students are still unprepared and are not knowledgeable in stewardship	No evaluation
Kerr et al, 2001	Letter to the editor United Kingdom	To understand the amount of contact time allocated to teaching about the rational use of antimicrobials at UK medical schools and the University of St Andrews	Research study described: postal survey	Medical students	Number of contact hours; methods of teaching	Number of hours dedicated varies greatly (0.5-22h); difficult to quantify exposure during teaching of other topics and in clinical setting; main methods of teaching was generally lectures, but also supplemented with tutorials and learning exercises, as well as self-directed learning	No evaluation
Le Normand et al, 1994	Research France	To develop a program to help teach the basic principles of antibiotic monitoring for time-dependent and concentration-dependent bactericidal molecules	Multidisciplinary tutorial programs. Students given clinical case information, and plan treatment. System evaluates students' choice and provides commentary to evaluate the efficacy of treatment	Does not state	Not stated	Programs are complimentary to conventional teaching	No evaluation
Lee et al, 2013	Review N/A	To summarize and discuss various strategies to minimize antibiotic resistance	N/A	Medical students post-graduate trainees, staff	Courses in numbers and days, number of inappropriate prescriptions, number of duplicative gram-negative coverage with iv fluoro-quinolones, duration of inappropriate use	Decreasing resistance requires involvement of students, staff, and the public. While much education has been targeted at staff and some at children, undergraduate training courses would be successful if the students are imparted with adequate knowledge, and trained in developing the right attitude and behavior. All health professions require teaching	No evaluation

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
Lee et al, 2015	Review N/A	To investigate recent studies on the effect of interventions for promoting prudent antibiotics prescribing,	N/A	Medical students and staff	Usage of diagnostic tests, choice of antibiotics, clinical outcomes (length of antibiotic treatment, length of stay, mortality)	There is no randomized control trial study assessing the effectiveness of educational programs for medical students. There is no study measuring the effectiveness of an educational program on prudent antibiotic prescribing for medical students	No evaluation
Luther et al, 2013	Letter to the editor United States	To increase appropriate antibiotic use	Antimicrobial stewardship pilot curriculum: didactic presentations and exam questions in USMLE format; clinical years have small-group activities	Medical students	N/A	N/A	No evaluation
McNulty, Cookson and Lewis, 2012	Program description United Kingdom	Examines what is currently being done in terms of antimicrobial stewardship in the UK / in Europe	Inclusion of hygiene and aseptic practice in the induction for the foundation years; infection control procedures are key competencies in second year; inclusion of infection control in appraisal for foundation year and specialist registrar trainees; infection control elements within the exams of Royal Colleges	Undergraduate, postgraduate, public, staff	N/A	The CMO is at the point where they are asking if it is indeed being taught / included at an undergrad and postgrad level	No evaluation
Philp, Wilford and Low, 1986	Research United Kingdom	To better define the scope of the failure for residents to prescribe rationally despite their lecture-based training	Research pharmacist examined ward prescription sheets and questioned residents about antimicrobial orders compared to labs if labs ordered	Residents	Number of antimicrobial prescriptions written; before or after labs; rational and appropriate prescription of antibiotics	Residents prescribed rationally when they had seen the labs but prescribed inappropriately if they did so before labs came back. Residents do not follow the methodology they were taught in class	No evaluation
Pulcini and Gyssens, 2013	Review N/A	To educate medical students on principles of microbiology, infectious diseases and clinical pharmacology, and on prudent prescribing of antibiotics	N/A	Medical students, children, junior doctors, staff	When should antimicrobial stewardship education start; who should educate; how should they be educated	Education should exist in medical school starting in year 3 of a 4 year program, not just in post-graduate setting	No evaluation
Pulcini et al, 2015	Research Europe	To educate European medical students; to determine antibiotic education in medical curricula	Questionnaire and interviews with lecturers to evaluate medical school curricula	Medical Students	Teaching principles for prudent antibiotic use in undergraduate curriculum; Association among curriculum, antibiotic use and/or rates of bacterial resistance at the country level	Prudent antibiotic use principles were taught in all but one school, but only 4/13 countries had a national programme. Interactive teaching formats were used less frequently than passive formats: clinical case discussions, active learning assignments, web-based server software learning platform, E-learning,	No evaluation

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
						role-play were used variably; lectures were used in all cases. Opportunities for implementation in curricula were variable. There was no significant association between the level of teaching of prudent antibiotic use and either prevalence of bacterial resistance, outpatient antibiotic use and total antibiotic use. Lack of time one of the main constraints preventing it from being included more heavily in curricula. There is wide variation even amongst students within the same country in terms of exposure to antibiotic prescribing principles.	
Shankar et al 2011	Program description Nepal	To improve teaching of antibiotics to medical students	Problem-based learning used to teach pharmacology with 10 developed subject areas that students should learn in pharmacology	Medical students	N/A	Rational use of antibiotics has been embedded throughout a small group module. The module with modifications can be considered for inclusion in other medical schools	No evaluation
Wright and Jain, 2004	Opinion United Kingdom	To review undergraduate medical education on AMR	Survey on knowledge of antibiotics and resistance were given to final year medical students before additional teaching. Spread teaching by medical microbiologists (tutorials)	Medical Students	Knowledge of antibiotics and of resistant organisms; no analysis given on interventions	Students do not always know the brand names of generic drugs; students had a good understanding of resistant organisms but overestimated antibiotics prescription rates in hospital. No analysis given on intervention	Level 2 of medical students, but no evaluation of the additional teaching
Bannan et al, 2009	Research Australia	To elicit attitudes of the ASP's aims, utility, educational value, effect on patient care and ease of use	Self-administered questionnaire, ASP program required receiving ID approval of restricted antibiotics, attitudinal and belief questions measured.	Interns, RMO and staff	Knowledge, attitudes and beliefs on the system; use of the system	98% of staff found ASP reasonable. Most believed it made teams think carefully about antibiotic choice. It was time-consuming and detracted from clinical duties. Intervention was believed by most to improve patient outcomes.	Level 1
Beylefeld and Struwig, 2007	Research South Africa	To improve medical microbiology teaching and students enthusiasm for it	Quiz-type board game	Medical students	Two questionnaire surveys, a focus group interview, direct observation and the nominal group technique	Game format effective in improving student engagement	Level 1

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
Cheunchom et al, 2016	Research Thailand	To identify knowledge, perception & attitudes concerning antimicrobial resistance & infection control among final year medical students	Questionnaire-based study among final year Thai medical students	Final year undergraduate medical students	Survey assessed student's perception and attitudes towards AMR, and knowledge of AMR/ infection control. Further educational activities and hospital structure were examined	Student's knowledge concerning AMR, appropriate usage and infection control was limited. Only half of students recognized the existence of an AMS program or infection control unit in their hospitals, highlighting poor access and gaps in current medical education at these institutions	Level 1
Gharbi et al. 2016	Research United Kingdom	To identify junior doctor's knowledge, attitude, behaviours concerning antimicrobial prescription so as to identify key areas to address future educational programs	Cross-sectional survey investigating junior doctor's antimicrobial prescribing practices & educational needs	140 Junior doctors, form 5 London hospitals	Survey assessed prescribing behaviour of junior doctors, prescribing education & support in the hospital through a needs- based assessment. Multiple logistic regression examined factors associated with confidence prescribing Abx as a junior doctor	A significant proportion of junior doctors reported prescribing of antimicrobials in the context of low self-perceived confidence and knowledge and had difficulty in accessing aid. 5 specific areas needed to bolster junior doctors practicing in secondary care. Specific areas of educational need included: principles of antimicrobial prescribing, diagnosis of infections, clinical review of patients c infections, prescribing in context of AMR & laboratory testing/ test results	Level 1
Haque et al. 2016	Research University of Sultan Zainal Abidin, Malaysia	Assess medical students' knowledge regarding antimicrobial resistance and prescribing and to identify any gaps in education	Cross-sectional, questionnaire-based survey	Medical Students (year 3, 4 & 5)	Questionnaire consisted of 21 questions to assess: confidence in prescription, AMR knowledge, amount of training in undergrad studies and self-reported antibiotics usage	There is an educational gap between theoretical input and clinical practice in terms of AMR and antibiotics prescription. The majority of students (88%) stated desiring more training in their current curriculum concerning antibiotic selection and theory.	Level 1
Hoque, Mostafa, Haque et al. 2016	Research Chittagong, Bangladesh	To gain insight of medical students concerning antimicrobial prescribing and resistance, assessing readiness from education at private school in Bangladesh	Cross sectional, randomized, questionnaire based study	Medical students (years 3, 4 & 5 (clinical year in Bangladesh)	Survey assessed student's confidence in AMR & prescription practices, knowledge, amount of training received in curricula and self-reported practices of antimicrobial usage	Students had a lack of confidence in the context of AMR/prescription practices due to a knowledge gap in the proper selection of antimicrobials.	Level 1

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
Minen et al, 2010	Research United States	To understand medical students perceptions of their medical education; to identify gaps in medical education	Online survey on perceptions and attitudes of their training in antibiotics. Curriculum had pharmacology and an infectious disease courses that included antimicrobial treatment selection	Medical students	Student opinions and preferences on importance of antibiotics and resistance, feedback and teaching; where students access knowledge; basic knowledge of organisms and resistance	Student recognition of importance of topic and want more instruction. Medical school curricula should be expanded to provide additional training timed with their clinical rotations. Students have no clear preference for digital reference use for self-directed continuing education.	Level 1
Nifakos, Tomson and Zary, 2014	Research Sweden	To investigate educational approaches using the real physical context to enrich the educational on antibiotics prescribing	Augmented reality using a drug box	Residents	Design-Based Research Methodology: problem analysis, investigation of information that should be visualized for the training session, and finally the involvement of the end users the development and evaluation processes of the prototype.	Must further examine how augmented reality could contribute to the improvement of competencies among healthcare professionals and decrease of antibiotics resistance. The prototype needs further development; it had a high level of acceptance amongst students	Level 1
Priyash-eelta et al. 2016	Research, letter to the editor United States	Evaluate medical trainees' knowledge & education regarding antibiograms	20-item survey	Postgraduate medical students (residents & interns)	Survey assessed resident/ intern's education surrounding antibiograms: comprised of knowledge- based questions (including antibiograms/ breaking point) & sources of education related to antibiograms	Study found that medical trainees receive limited education surrounding AMR/AM prescription – specifically, this study highlights that education- surrounding antibiograms is deficient & requires further coverage in curricula. Almost all residents/interns were familiar with the definition of an antibiogram, but only 62.2% correctly identified the definition of a 'breakpoint,' and 77.9% knew how to obtain their institution's antibiogram.	Level 1
Marwick and Nathwani , 2007	Letter to the editor United Kingdom	To improve appropriate antibiotic prescription	Promotion of local good practice guidelines, audits of knowledge and behaviour. An outcome based web-based program for teaching and reflecting on learning of antibiotics prescribing	Medical students	Student and staff feedback; student knowledge evaluated through exams	More clinically focused teaching through such web-based approaches can effectively improve students knowledge	Levels 1 and Level 2
Valente et al, 2009	Research Brazil	To integrate basic Bacteriology with mechanisms of action of antimicrobial agents	Board game to teach students about antibiotics and resistance	Medical students and pharmacy students (undergraduate)	Knowledge pre- and post-intervention; survey on whether students liked the game, and whether they	There was an increase in the number of right answers and a decrease in the number of unknown answers. There were no significant differences between the	Level 1 and 2

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
					found it an effective learning tool, etc.	courses.	
Welch et al, 2000	Research United Kingdom	To promote rational antibiotic and analgesic prescribing for non-inpatients attending an emergency department	Survey, intervention (prescription pad including a summary of clinical condition) reviewed by panel of experts and rated for appropriateness, followed by educational period, which included lectures, discussion groups, and guideline promotion. Survey and review were repeated	Junior medical officers	'Non-inpatient' prescriptions were collected before education and afterwards.	Not statistically significant improvement in antibiotic prescribing trends; use of guidelines did markedly increase. A method has been developed to educate JMOs on therapeutics in the ED that led to a trend in improvement in prescribing of antibiotics but little change in analgesic prescribing. The program was very well accepted by the JMOs	Levels 1 and 3
Temte et al, 1999	Research United States	To improve viral surveillance and improve family medicine residents prescribing of antibiotics	Viral surveillance program as well as detailed educational seminar on respiratory viruses. Chart review to evaluate antibiotics prescription rates and upper respiratory infections	Residents	Familiarity with system and evaluation of training in terms of knowledge provided and its usefulness; rates of antibiotic prescribing in senior residents	By PGY-3 year, 79% felt their education and training had provided adequate knowledge. Most knew about the surveillance program but only 42% pay attention to surveillance reports. 86% had obtained specimens for viral culture. Educational intervention, while did not set out to change physician behaviour, did have this effect.	Levels 1 and 3
Bain 1984	Program description United Kingdom	To assess the diagnosis/treatments for acute earache in children developed by a trainee before and after 6 months with a trainer	24 Trainers and their Trainees were asked to examine the case histories of 5 children with 24 hours of ear ache	Trainers and trainees (does not state level)	Prescription rates of different medications	Fall in trainees prescribing of antibiotics for otitis media (although not statistically significant), but this was correlated with an increase in prescribing of decongestant-antihistamines	Level 2
Dawson, Bennett and Ongley, 2010	Letter to the editor United Kingdom	To evaluate the use of e-learning modules on antibiotic prescribing	A mandatory induction module; a module on antibiotic prescribing	All staff, including residents and medical students	Use of e-learner package and effect on on-site training	The modules have enabled the junior doctors to become familiar with Trust procedures and IPC and antibiotic policies, and have reduced the time required for on-site induction training	Level 2
Faryna, Wergowske and Goldenberg, 1987	Research United States	To understand the impact of therapeutic guidelines on outpatient prescribing patterns of internal medicine residents	A one-page set of treatment guidelines was designed by internal medicine staff and placed on the desks of their examining rooms. A pre and post intervention survey was collected	Residents	Antibiotic choice and appropriateness	Pre-intervention showed 50% of antibiotic choices were inappropriate, but there was no significant difference in pre- and post-intervention antibiotic choices. The more experienced a resident, the less appropriate the antibiot-	Level 2

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
						ics prescription pre-intervention, but there was no difference after between experience levels. The guidelines did not result in a significant decrease in proportion of inappropriate antibiotic. prescriptions. More effective surveillance is needed in the area of outpatient antibiotic prescribing by residents; audits are a practical way to monitor prescribing behaviour	
Feucht et al, 2003	Research United States	To improve IV vancomycin and fluoroquinolone prescribing practices with guidelines. (ie: encourage early discontinuation of inappropriate use or duplicative gram negative coverage)	Monthly or semi-monthly conferences on antimicrobial therapy and resistance, as well as guidelines and current hospital practices. Antibiotic use monitoring by clinical pharmacist with consultation if use deemed inappropriate. Reprints of the guidelines were also placed in the medicine physician conference rooms.	Residents and staff	Number of metrics including number of inappropriate prescriptions, length of course, and number of antibiotic courses overall	The intervention decreases unnecessary duplicative regimens, number of courses overall of some antibiotics, courses over 5 days, and inappropriate prescribing. Appropriate educational intervention programs can alter prescribing patterns in residents, particularly in early discontinuation of inappropriate therapy and altering prescribing practices of fluoroquinolones.	Level 2
Huang et al, 2013	Research China	Purpose of survey: to get an overview of the students' understanding of antibiotics, and to compare the medical students' and non-medical students' knowledge, attitude and behaviour towards antibiotic use	Curriculum gives intro of infectious diseases. Antibiotic prescription is supervised by clinicians during clinical internship. Gave questionnaire on: knowledge of antibiotics, attitude towards antibiotic use, perception of public education and practice towards antibiotic use.	Medical students	Knowledge of antibiotic use; attitude and public education on usage of antibiotics; behaviour of using antibiotics	Medical school did improve knowledge of antibiotic use; majority of students thought antimicrobial resistance was a problem in China and results from antibiotic abuse and more public education is necessary. Medical students scored worse than non-medical students on behaviour towards use of antibiotics. Medical students got better as they progressed through their years indicating that the schooling improved their knowledge	Level 2
Ikai et al, 2012	Research Japan	To understand the effect of postgraduate education on physicians' adherence to the guidelines or on patient outcomes.	Systematic lectures and case-based discussions. A hospital-wide restricted formulary to decrease carbapenem. Analysed via chart review.	Residents	Appropriateness of antibiotics prescribed, reasons for inappropriate use	More frequent blood, sputum cultures and gram stains; less frequent use of broad spectrum antibiotics as initial empiric therapy; median length of stay was shorter after intervention; de-escalation from parental to oral was not signifi-	Level 2

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
						cant; more cases were treated with oral abs.	
Pisano et al. 2016	Research United States	Study aims to augment reach & boost antimicrobial stewardship through utilization of social media	Pre- and post- intervention surveys – including 20 questions on antibiotics & infectious diseases and awareness of ASP initiatives, social media usage & attitudes surrounding antimicrobial resistance	55 internal medicine residents	Pre- and post-intervention surveys after the ASP social media intervention (which included trivia questions on antimicrobial resistance/ antibiotics prescription, links to teaching articles or internal content on ASP website – using Twitter & Facebook)	Study concluded that social media proved to be a valuable tool to reinforce ASP initiatives and education, while encouraging the use of ASP so as to promote Antimicrobial mindfulness in clinical practice. antibiotics knowledge scores increased following the social media education intervention, and access to ASP increased from 70% - 94%. Further, more IMRs indicated using the ASP clinical pathways more frequently post- intervention	Level 2
Rawson et al. 2016	Research United Kingdom	To investigate the coverage of AMS across UK clinical postgrad curricula & assess quality of education	Cross-sectional analysis & quality assessment	Postgraduate medical students (37 specialties; inter-specialty analysis performed)	37 Specialties assessed: topics & individual learning points relating to antimicrobial stewardship & resistance were extracted for each specialty, and these were then quality assessed, followed by inter-specialty analysis	Overall coverage of antimicrobial stewardship & resistance is relatively poor across the majority of UK postgraduate clinical training curricula, with little depth of learning enacted. Of the 37 specialties assessed, 2,318 topics & 42,527 learning points were identified – of these, 0.3% topics & 0.4% learning points were related to antimicrobial stewardship/resistance. In contrast, primary care, which is responsible for the highest proportion of antimicrobial usage, only had 0.15% antimicrobial stewardship/resistance learning points. On quality assessment, 60% of learning points required knowledge only, with no demonstration of behaviour in clinical practice.	Level 2
Zamin, Pitre and Conly, 1997	Research Canada	To assess the effect of introducing a route conversion program on the prescribing of antimicrobials for the treatment of respiratory tract infections and skin/soft tissue infections	General medicine wards at a tertiary care health centre had a route conversion program had the insight of infectious disease physicians and microbiologists, as well as pharmacists	Medical students post-graduate trainees, staff	Clinical and laboratory parameters related to the status of the infection compared with course of therapy; patient's ability to meet the criteria established in the	Even after program introduction, the number of days that IV therapy was continued, despite the appropriateness of oral therapy, was reduced. The program had a positive influence on antimicrobial prescribing behaviour in the population studied.	Level 2

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
					guidelines; number of days of IV therapy		
De Souza V et al, 2006	Research Ireland	Medical school curriculum: to teach students proper antimicrobial prescribing. Overall: to evaluate factors that influence prescribing by non-consultant hospital doctors	Curriculum design / influences on young doctors that is discussed: the practices of senior colleagues on their teams; personal experience later in their career; undergraduate lectures; hospital guidelines	Medical students and postgraduate trainees	Processing and mastery of medical microbiology learning content, enjoyment derived from intervention, Qualitative evidence of positive affect generated by intervention	While undergraduate training in medical microbiology provided information on infections, it left interns insufficiently trained to make autonomous antimicrobial prescribing decisions. Formal undergraduate education on antimicrobial agents, rationale for antimicrobial use, existing hospital guidelines and concerns about emerging resistance appear to be minor influences. Those trained in low income countries had greater knowledge and autonomy in their prescribing	Level 3
Irfan et al. 2015	Research Canada	Identify risk factors for unnecessary prescription and to assess impact of educational intervention focused on prescription of antibiotics	Quasi-experimental study, with a control group	Medical residents	Study compared baseline period of patients with positive urine cultures to educational intervention period to compare appropriate antibiotic prescriptions	Educational intervention was effective in the reduction of unnecessary antibiotic use – 52% of control interventions were inappropriately prescribed compared to 8% following intervention	Level 3
Lee et al, 2014	Research Canada	To optimize antibiotic use through trainee-led time-outs	While receiving monthly education on antimicrobial stewardship, residents adjusted patients' antibiotic therapy through twice-weekly time-out audits using a structured electronic checklist	Residents (medical students were on the team during the audit, but it is unclear whether they participated)	Cost savings, comfort with antibiotic prescribing, patient prescription rates	$70,000 savings associated with 1 hour of faculty time and 8 hours of resident time. 80% of residents adhered to the auditing program and believed it improved their comfort with antibiotics and provided clinical value. 1 in 7 patients had their antibiotics changed after the first audit. Rates of C diff decreased. No mention of medical students directly	Level 3
Légaré et al, 2011	Research Protocol Canada	To improve the use of antibiotics in family medicine treatment of acute respiratory infections	Web-based tutorial followed by interactive workshops; addressed clinical decision-making process regarding antibiotics treatment	Residents and staff	Proportion of patients reporting a decision to use antibiotics immediately	N/A	Level 3
Main and Koerner, 2012	Letter to the editor United Kingdom and	To reduce levels of antimicrobial resistance	Audit; using a restricted group of antibiotics	Residents	Incidence of multi-drug-resistant microbes	Reduced incidence of multi-drug-resistant microbes; not enough evidence to expand	Level 3

Author, year	Article type and location	Purpose of intervention	Intervention design	Target learner group	Variables of interest	Results and conclusions	Kirkpatrick evaluation level*
	Europe						
McLellan et al. 2016	Research United Kingdom	Investigate whether & how structured feedback sessions can increase rates of appropriate antimicrobial prescribing by junior MDs	Participants randomized to intervention (pharmacist-led feedback sessions) and control (routine practice) 2 days/week for 6 months, mean normalized prescribing rates & qualitative interviews	Junior doctors (post graduate residents) in their first year of training	Researchers assessed normalized rates of prescription. Further, thematic analysis of qualitative interviews was completed to gain insight into the feedback workshops	Study found that the Pharmacist-led feedback intervention augmented appropriate prescription patterns in junior doctors, by acting as a positive stimulus within a complex network of behavioural influences. The authors conclude that prescribing behaviour is adaptable and can influence best practice guidelines by reducing suboptimal antimicrobial prescribing	Level 3
Zwar, Gordon and Sanson-Fisher, 1995	Research Australia	To improve rational prescribing of antibiotics and benzodiazepines	Randomized control trial evaluating a seminar on rational prescribing focusing on skills and knowledge. Included: information including reference to guidelines, process skills and feedback on performance. Group discussion then held and feedback on performance given.	Residents	Rate of antibiotic prescription for all conditions; prescribing of antibiotics for URTI, choice of antibiotics for conditions including tonsillitis, sinusitis, acute otitis media, etc. Benzodiazepine prescription for all conditions	Group educational approaches to influence prescribing can be effective. Decrease in antibiotic prescribing, but often non-significant decreases in intervention group and increases in control. Further research is needed to assess whether prescribing behaviour is affected by feedback, guidelines, reminders, etc.	Level 3
Zwar et al, 1999	Research Australia	To examine effectiveness of an intervention to reduce antibiotic prescribing in GP trainees for undifferentiated upper RTI and improve antibiotic choice	Individual prescriber feedback, followed by further resources and further visits. Prescriber feedback and educational outreach also given.	Residents	Diagnostic behaviour	Antibiotic prescribing by the intervention group declined, while the control group increased. Prescribing in agreement with accepted guidelines increased in the intervention group, but decreased in the control group. Prescriber feedback and management guidelines influenced antibiotic prescribing and choice of antibiotic.	Level 3
Thamlikitkul et al, 1998	Research Thailand	To reduce inappropriate prescribing in a hospital setting	Information feedback and antibiotic guidelines through information sessions. Data from patients prescribed antibiotics was collected before and after educational intervention	Residents, staff, and final year medical students	Frequency of antibiotic use and their cost pre-and post-intervention	22% reduction in antibiotics use in in-patients; 23% in outpatients. Most antibiotics are prescribed by residents, GPs in outpatient clinics and final year medical students. The educational program was effective.	Level 3 and 4

*Kirkpatrick Levels of Evaluation: (1) reaction (satisfaction or happiness; what participants thought of the educational intervention), (2) learning (change in attitude and/or knowledge or skills gained assessed by test or demonstration), (3) behaviour (transfer of attitude, knowledge and/or skills to workplace or clinical setting), and (4) results (patient care affected or societal impact due to participation in the educational intervention evaluated).[32]